# Gravity-induced decay

Sergei Viznyuk

**Abstract**

I suggest an object acted on by classical (i.e. non-coherent) force, in gravitational field, unavoidably decays. I estimate decay rates in some scenarios.

Quantum phase shift between superposed states with different space geometries in gravitational field inspired interest (Penrose, 1996) as well as controversy (Gao, 2013; Bonder, Okon, & Sudarsky, 2016; Pikovski, Zych, Costa, & Brukner, 2015) since at least early 1960-ies when (Feynman, 1962) first talked about role of gravity in breakdown of quantum mechanical behavior. Despite the controversy, the nature of the phenomenon appears mundane: the states with different space geometries in gravitational field experience phase shift with respect to each other. If the shift is larger than the de-Broglie wave packet length the interference between packets with different space geometries vanishes. It is the same effect as disappearance of interference pattern in two-slit experiment when difference in optical lengths between two paths exceeds the coherence length of the light source (Figger, Meschede, & Zimmermann, 2002). In such case, wave packets (e.g. laser pulses) appear as if they travel down only one of the paths, as do classical particles. However, the interference amplitude can be easily restored by introducing phase delay into one of the optical paths. Perhaps one should not equate phase shift between wave packets or decrease in interference amplitude with true de-coherence, which is an irreversible loss of phase relationships between constituent states.

The observable effect of true de-coherence is disintegration of the object into wave packets with no phase relationship between the packets. Such packets behave as separate objects.

True de-coherence arises if phases of constituent pure states no longer predictably relate to each other, e.g. as a result of random dispersion. Random phase dispersion can be associated with:

1. Scattering (Uys, et al., 2010; Schlosshauer, 2007)
2. Brownian motion (Paz, 1994; Hornberger, 2009)
3. Dispersive media (Antonelli & al, 2011; Salemian & Mohammadnejad, 2011)

In this article I look into phase dispersion introduced by non-coherent coupling between external non-gravitational fields and object's constituent pure states, in the presence of gravitational field. According to (Einstein, 1907) equivalence principle, the effect of the external non-gravitational force on the object at rest in a [uniform] gravitational field is indistinguishable from the effect of the same force on the object away from gravitating bodies, in object's [accelerating] reference frame. Thus, the influence of non-gravitational fields does not depend on presence of [uniform] gravity. The inevitable conclusion is that any change to the state of the object, such as phase dispersion between constituent pure states, can only be caused by non-gravitational fields:

> *It is clear, …, that, while some kind of decoherence might happen in specific experimental situations, gravity, … is never the agent that causes the effect.*
>
> (Bonder, Okon, & Sudarsky, 2016)

Nevertheless, I suggest, gravity plays an important role, by establishing *preferred basis* in system's state vector space. Phase dispersion by coherent coupling between external field and pure states retains coherence of the wave packet. If coupling is non-coherent, as e.g. with environment heat bath, the phase dispersion includes random phase noise which, over sufficiently long time, results in true de-coherence of the wave packet, and decay of the object is represents.

To demonstrate the principal feature, consider the object is in a stable state $\Psi$ if no external fields. If object is free-falling in a gravitational field, with respect to lab frame the state $\Psi$ is a superposition of eigenstates $f_k$ of Hamiltonian $\boldsymbol{H}$ with field, i.e. in the *preferred basis*:

$$|\Psi\rangle = \sum_k |f_k\rangle\langle f_k|\Psi\rangle \tag{1}$$

Thus in a lab, $\Psi$ is no longer a static state, as can be seen from solution to Schrodinger's equation:

$$\Psi(t) = exp\left(-i\frac{\boldsymbol{H}}{\hbar}t\right)\cdot\Psi(0) = \sum_k |f_k\rangle\langle f_k|\Psi(0)\rangle\cdot exp\left(-i\frac{E_k}{\hbar}t\right) \tag{2}$$

An observer performing measurement of object's vertical coordinate $z$ will find the expectation value change according to:

$$z(t) = z(0)\sum_{j,k} P_j P_k \cdot cos\left(\frac{E_j - E_k}{\hbar}t\right) \quad \text{, where} \quad P_k = |\langle \boldsymbol{f}_k|\Psi(0)\rangle|^2 \tag{3}$$

A two-level system is sufficient to demonstrate the main feature (Viznyuk, 2014):

$$z(t) = z(0)\cdot\left(P_1^2 + P_2^2 + 2P_1P_2\cdot cos\left(\frac{E_2 - E_1}{\hbar}t\right)\right) \tag{4}$$

From (4) the relation with acceleration of gravity $g$ is:

$$g = \left|\frac{\partial^2 z}{\partial t^2}\right|_{t=0} = \left(\frac{E_2 - E_1}{\hbar}\right)^2 2z(0)P_1P_2 = \omega^2 r \tag{5}$$

, where $r = 2z(0)P_1P_2$ ought to be taken as a distance (radius) to the center of gravity at $t = 0$, and $\omega = \sqrt{g/r}$.

Now consider the object is acted on by an external non-gravitational forces keeping the object around fixed position in a lab frame. If external fields couple coherently, the evolution of object's state $\Psi(t)$ is still described by (2), where $f_k$ are eigenstates of Hamiltonian with all fields included. With non-coherent coupling, the phases $\varphi$ of $f$-states no longer relate to each other as

$$\varphi_j(t) - \varphi_k(t) = \Delta\varphi_{j,k} = \frac{E_j - E_k}{\hbar}t = \omega_{j,k}t \tag{6}$$

Instead, non-coherent coupling can be modelled as a random phase walk, with phase difference $\Delta\varphi_{j,k}$ changing by $\pm\left(\theta_{j,k} = \omega_{j,k}\tau_{j,k}\right)$ during single act of interaction with external field. Here $\tau_{j,k}$ has a meaning of *mean free time* between interactions, with $S_{j,k} = 1/\tau_{j,k}$ being a *scattering rate*. During time $t$ there is $n_{j,k} = t\cdot S_{j,k}$ scattering events, each with probability $p = 1/2$ to increment phase difference $\Delta\varphi_{j,k}$ by $\theta_{j,k}$ in positive or negative direction. After $n_{j,k}$ scattering events phase difference $\Delta\varphi_{j,k}$ will be within *standard deviation* $\sigma_{j,k}\theta_{j,k}$ of its *coherent* value, where $\sigma_{j,k}^2$ is the variance of binomial distribution $\sigma_{j,k}^2 = n_{j,k}\cdot p\cdot(1-p)$. So, instead of (6), for non-coherent coupling I have:

$$\Delta\varphi_{j,k} \sim \omega_{j,k}\cdot\sqrt{\tau_{j,k}\cdot t\cdot p\cdot(1-p)} = \frac{\omega_{j,k}}{2}\sqrt{\tau_{j,k}\cdot t} \tag{7}$$

Once random dispersion (7) grows to $\Delta\varphi_{j,k} \geq 1$ the $f_j$, $f_k$-states can be considered de-coherent with respect to each other. From here I estimate time $t_d$ for the object to decay, considering it a simple two-level system as in (4), (5):

$$t_d \sim \frac{4}{\omega^2\tau} = \frac{4r}{g\tau} = \frac{4r}{g}S \quad \text{, and decay rate} \quad D = \frac{1}{t_d} = \frac{g}{4r}\tau = \frac{g}{4\cdot r\cdot S} \tag{8}$$

Eqs. (7-8) has been derived in approximation of large number of scattering events per rotation period $2\pi/\omega$, i.e. in approximation $S \gg \omega$. In the opposite $S \ll \omega$ case I expect: $D \to 0$ as $S \to 0$. The inverse proportionality of decay rate $D$ on de-coherent scattering rate $S$ in (8) can be viewed as manifestation of quantum Zeno effect (Misra B., 1977). Each scattering event constitutes the *measurement by the environment*. The more frequent are the measurements performed on the object, the more likely the object will be found in its initial state after fixed elapsed time. Furthermore, the effect may not even be so "quantum" in nature. I can simulate it using the following experiment: take a [fragile] wine glass and try to keep it vertically around the same height with respect to lab floor by applying periodic kicks from below using some hard-surface object, e.g. a wood board. In the *mean free time* between the kicks the wine glass will be in free fall. The more frequent are the kicks, the lesser distance the wine glass will fall in between the kicks, the lesser is the force of each kick required to return the wine glass to its initial position. In the limit of infinite frequency of kicks, the wine glass will be simply standing steady on hard surface. It can stay in such position forever. However, if the frequency of kicks is decreased, in the *mean free time* the wine glass would fall greater distance. Each kick would have to be stronger to return wine glass to its initial position; and with stronger kick it is more likely the wine glass would eventually break into smaller pieces. As I expect, there is also a second limit, when $S \to 0$; $D \to 0$; corresponding to the case when wine glass is allowed to fall indefinitely without experiencing kicks, and that would preserve wine glass too.

It is conceivable (8) could be applicable to any object, including elementary particles which are otherwise considered stable, such as electrons and protons. I shall estimate $t_d$ from (8) in some scenarios, using input parameters from the cited sources:

| Scenario | Distance $r$ to the center of gravity ($m$) | Acceleration $g$ of gravity ($m \cdot s^{-2}$) | Scattering rate $S$ ($s^{-1}$) | Decay time $t_d$ |
|---|---|---|---|---|
| electron in Sun's photosphere | $7 \cdot 10^8$ [21] | 274 | $5 \cdot 10^9$ [10] | $1.6 \cdot 10^9$ *years* |
| electron in Sun's corona | $7.1 \cdot 10^8$ [21] | 267 | $7 \cdot 10^1$ [10] | 24 years |
| proton in Sun's core at the maximum gravity location | $1.19 \cdot 10^8$ [18] | 2342 | $10^{12}$ [9] | $2 \cdot 10^{17}$ s |

With solar mass distribution (Stix, 2004), the gravity reaches maximum of $2342\ m \cdot s^{-2}$ at about 0.17 of solar radius from the center of the Sun. The proton collision rate in Sun's core is estimated from $10^{12}\ s^{-1}$ (Knapp, 2011) to $2 \cdot 10^{15}\ s^{-1}$ (Mullan, 2009). Thus from (8) the decay rate of protons in Sun's core could range from $2.5 \cdot 10^{-21}\ s^{-1}$ to $5 \cdot 10^{-18}\ s^{-1}$. The claimed hydrogen fusion rate of $(1-5) \cdot 10^{-18}\ s^{-1}$ (Knapp, 2011; Mullan, 2009) in Sun's core lays right in that range. If the presented reasoning is valid, the thermonuclear fusion might not be the primary factor behind Sun's radiative output. Indeed, as radiative modes have higher entropy than heavy nuclei the Second Law of Thermodynamics favors Sun evaporating into thermal radiation rather than forming iron core and turning into a white dwarf or neutron star, a relatively low entropy states. Also, the presented estimates show the proposed particle decay rates in Sun's corona are many orders of magnitude higher than in Sun's photosphere, which may explain why the temperature of Sun's corona is $(1-2) \cdot 10^6 K$, and up to $2 \cdot 10^7 K$ in the hottest regions, in comparison with photosphere which is about $5800\ K$.

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