The Mössbauer effect: a new theory. Part 2 --Draft

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The Mössbauer effect: a new theory.

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Part 2 -- *Draft*

Abstract – The Mössbauer effect, based on the variation in resonant absorption of gamma radiation (emitted partially in a very narrow wavelength interval) (Fig. 1, 2), reveals the energy levels of that single atom whose nucleus has absorbed a gamma photon without energy loss. Bonds and states of the atoms, far from this atom are not revealed. The hypothesis is that the Mossbauer effect is possible thanks to the intervention of the energy and momentum of zero point phonons, that are present in all the atoms of the lattice. The same intervention can happen from thermal phonons (**n**) where the probability for transitions n↔ n occurs. Most important are high energy phonons, with short wavelength. No phonon is created so that the energy of the lattice is conserved with a "loan" that is returned during the time interval, allowed by the uncertainty principle. A gamma quantum (the same goes for a neutron) affects an atom. This atom, if it were not bound in a lattice, would recoil. But instead, if the atom is bound in a lattice, it would have to transfer energy and momentum to the lattice, starting from the closest atoms. This transfer occurs by creating phonons, the quanta of vibration that spread at sound velocity. Nothing happens in the Mössbuaer effect. It is not true that it involves the other atoms of the lattice because the phenomenon occurs even if the hit atom is in a nanoparticle that does not have enough mass to hide the recoil. The hit atom hosts all the zero-point phonons (N-1) of the lattice (N atoms).
In order the lattice remains rigid, in the struck atom must be neutralized the impulse received. This can be obtained using a zero point phonon that is parked around him. But these zero point phonons could never be used. True, but for the uncertainty principle it can be done within the time allowed. Then everything goes back to the way it was before, but in the meanwhile the Mössbauer effect has occurred.
The Mössbauer effect shows what happens near and around the atom whose nucleus have absorbed a gamma quantum. For the same atom happens a momentum compensation to neutralize the pulse received. All to obey a conservation principle in the fluctuations of the zero point phonons. But all this is just mysteriously encoded in the Schrödinger time dependent equation, as we shall see from its analytic and numeric solution for an hypothetic case.

1 – Introduction

In **Part 1** we have noted the existence of two important experimental results that make current theories about Mössbauer effect unacceptable, all regarding the instantaneous collaboration of all the atoms of a lattice.

1) no Mössbauer spectrum does a shift appear due to the recoil (Fig.1 [1]), however small is the mass of the nanoparticle that houses the atoms absorbing gamma photons, impulse conservation would not be respected.

2) reducing the mass of the nanoparticles the absorption of the gamma photons is attenuated (the Mossbauer diagram area is reduced) even if, as we have said (**Part 1**), there is no shift by recoil even if the mass of the particle would not be able to hide the recoil (Fig. 1).

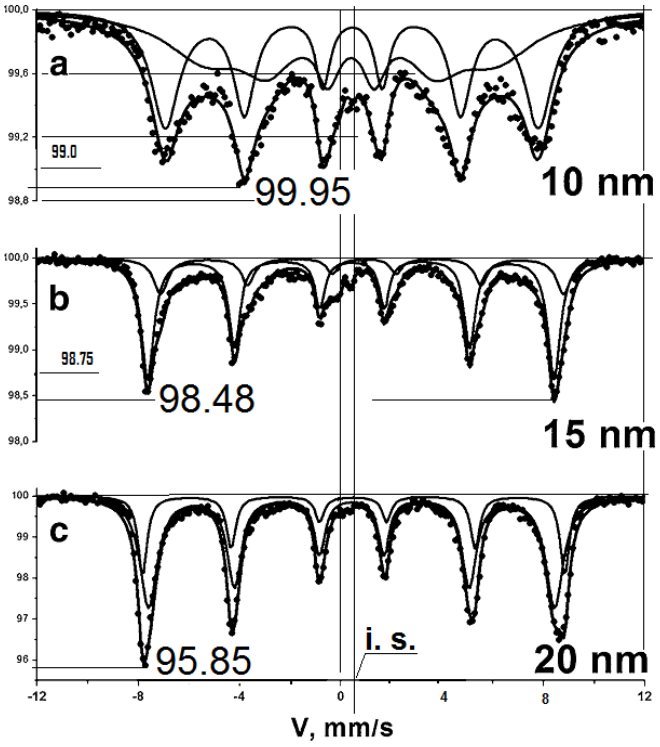

Fig. 1 – Mössbauer spectra of 10÷20[nm] nanoparticles measured at 78 K. When the dimension is reduced the diagram area is also reduced but no shift of the area barycenter appears. (Gabbasov et al. [1])

In **Part 2** we first examine the negative consequences caused by the belief that there is a sudden (and impossible) collaboration between the atoms of a lattice. We will then illustrate the present theory that involves the intervention of energy and momentum of the zero point phonons of the atom that emits or absorbs a gamma photons in the Mössbauer effect, that is shown by the above diagram (Fig. 2)

The appearance of the narrow line of irradiation and the same for absorption, (about 10^5 less than R) would not have been conceivable and undetectable without the chance discovery of Mössbauer. As known, the discovery was made by cooling the source and the absorber in an attempt to separate radiation and absorption,

narrowing the two areas indicated as “phonon wing” (Fig.2). The cooling had the opposite effect: the absorption of gamma rays increased.

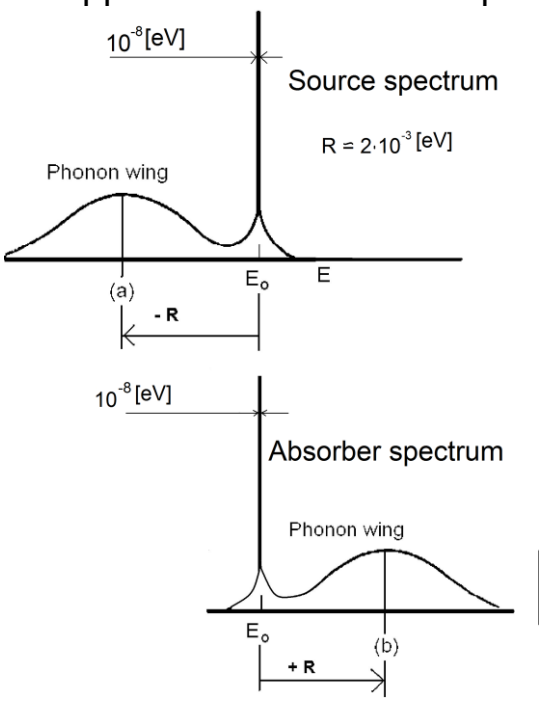

Fig. 2. Total gamma radiation and absorption spectra (schematic). R - recoil energy

Appear two unknown peaks, one in emission and one in absorption at the same wavelength.

We have found [2, 3] that a harmonic oscillator has a quantum “stiffness”, unknown and impossible in classical mechanics. But the Mössbauer effect does not only make use of a "quantum rigidity" to occur, for nanoparticles, it apparently must also violate the conservation of the impulse, which is impossible in both classical and quantum mechanics.

The question is: *how the impulse received by the nucleus, when a gamma photon is emitted or absorbed, is neutralized?*

In the current theory, the impulse would be transmitted to the entire mass of the lattice and then "diluted" until it was not measurable.

The proof of the impossibility of explaining the Mössbauer effect, with actual theory, is given by the examination of the gamma absorption spectra of the nanoparticles with an insufficient mass to justify the absence of recoil (see **Part. 1**, also Fig. 2).

To verify the condition of insufficient mass, the Mössbauer spectra relating to nanoparticles were examined. It must be remembered that the spectrum of the lattice oscillations of a nanoparticle is not comparable to a continuous spectrum as in a large solid (bulk).

The belief, founded on the collaboration of all the atoms of the lattice, goes back to Mössbauer himself. This is an erroneous belief that, until now, no one was able to correct. As seen from this misconception, the Mössbauer effect remained a mystery of physics for sixty years. Since the Mössbauer effect tells in great detail the

state of the atom whose nucleus has absorbed a quantum of gamma radiation, it would have been obvious to assume that the cause of the apparent rigidity of that nucleus where to be found in the same atom to which that nucleus belongs. But what we find in an atom, inserted in a lattice, to give this “quantum rigidity”?

2 - Zero point phonons in nanoparticles

The study of nanoparticles was the basis of the critique of the current theory regarding the Mossbauer effect. We resume the study of nanoparticles:
It is well known that the vibrational density of states (DOS) forms a continuous band in bulk solids, and at low energies is well described by the Debye law. However, in small crystals the finite size leads to a discretization of the phonon spectrum. This is strongly manifested at low frequencies where the separation between modes may become larger than their width, and no modes exist below the lowest vibrational frequency (Fig.3).

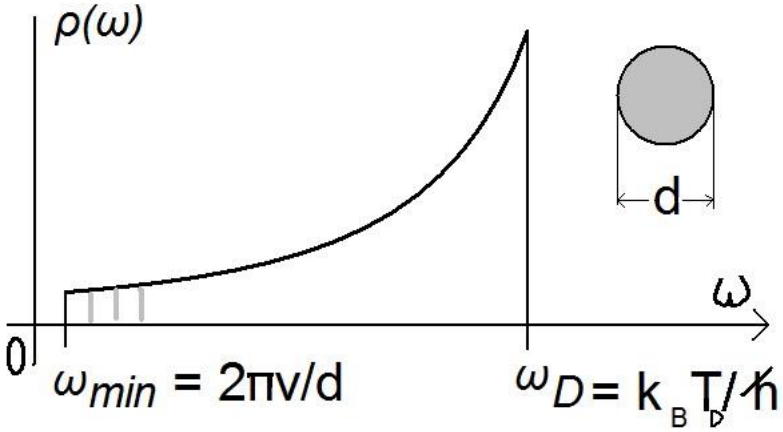

Fig. 3 - A nanoparticle of diameter **d**, in which the speed of sound is **v**, has no oscillation frequencies lower than $\boldsymbol{\omega_{min}}$. Obviously this spectrum of possible frequencies is also the spectrum of the real zero point oscillations present in all the atoms of the nanoparticle.

We shall refer to the frequency $\boldsymbol{\omega_{min}}$ of the lowest vibrational mode as the acoustic ‘gap’. The density of frequency $\varrho(\boldsymbol{\omega})$ in discrete form is given by:

$\varrho(\boldsymbol{\omega})=\sum_{n=1} 3N\boldsymbol{\omega}^2/(\omega_D{}^3-\omega^3{}_{min})$, where $\varrho(\boldsymbol{\omega})$ is the density of states versus the frequency $\boldsymbol{\omega}$.
A spherical nanoparticle of diameter **d** cannot support internal vibrations at frequencies less than about $\boldsymbol{2\pi v/d}$, where v is a characteristic bulk sound velocity (Fig. 3). Any property of the nanoparticle that depends on the vibrational spectrum, such as its thermodynamic properties or electron-phonon dynamics, will be very different at low energies than in bulk crystals. This will be especially true for nanoparticles only weakly coupled to their surroundings.

The phonon emission rate at frequencies less than that of the lowest internal vibrational mode, i.e., in the acoustic 'gap' (**0 - ω_{min}**) is zero. **In small crystals** the finite size leads to a discretization of the phonon spectrum (Fig. 3). This is strongly manifested at low frequencies where the separation between modes may become larger than their width, and no modes exist below the lowest vibrational frequency **ω_{min}**. The discrete DOS is expected to change dramatically many physical processes involving low frequency phonons, but are not changed the properties at high frequencies that are supposed to be the possible cause of Mὸssbauer effect. The hypothesis is made that an impulse does not create phonons, mainly thanks to the intervention of the momentum of the zero point high frequency phonons, that exists in bulk and in nanoparticles. If we reduce the mass of the crystal, thus reducing the number N of the atoms it contains, we will have fewer frequencies ((N-1) zero-point frequencies for each atom) of the crystal. The consequence is a reduction in the probability of elastic emission/absorption (Fig. 1, 3), which however will also occur with a lattice composed of a single atom, linked to a large mass (physical model of Fig. 4) and therefore with a single oscillation frequency (but only for collinear pulse).

3 - New Theory

Subtle is the Lord….. Really, until now, we do not know the physical mechanism that explains the Mὸssbauer effect. Indeed, from the beginning it was erroneously thought that there was the collaboration of all the atoms of the lattice. "*Subtle is the Lord*" Einstein said. But in the Mὸssbauer effect, the Lord was more subtle than usual. First of all the poor fancy of Mὸssbauer himself intervened and secondly the fact that the zero-point phonons, N-1 for each atom of the lattice (with N atoms) and all "parked" in each atom of the lattice, intervene not with their mass, but for their contribution to generating the dense zero point phonons spectrum. This concept was criticized [4].

In addition to the transition probability $P_{0\text{-}0}$, which is very high at low energies (Fig. 5), we must not neglect the transition probabilities $P_{n\text{-}n}$, that prevent the generation of new phonons even at temperatures higher than 0 K. For high N the spectrum of phonons is continuous, therefore also the Mὸssbauer effect is stronger, but experimentally it also occurs for N so low (nanoparticles) that the recoil shouldn't be not negligible, but it never appears (see **Part 1**).

Failure to understand the true nature of the Mὸssbauer effect was the cause of over sixty years of senseless research on the attempt to reveal low-energy neutrinos that arise with the decay of Tritium, as we shall see in a later paper.

In small crystals the finite size leads to a discretization of the phonon spectrum. This is strongly manifested at low frequencies where the separation between modes may become larger than their width, and no modes exist below the lowest vibrational frequency ω_{min}. The discrete DOS is expected to change many physical processes involving low frequency phonons, but the properties due to the high frequency phonons, as the interactions with a sudden pulse, are not changed (i. e. the interaction with gamma quantum mechanical pulse).

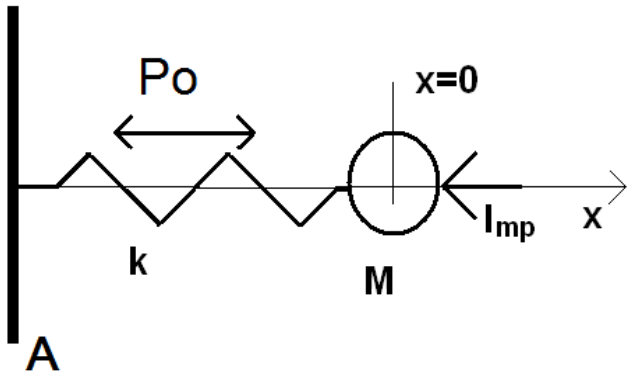

Fig. 4 The mass M is linked to the rigid structure **A** with an elastic constraint **k**. The $\mathbf{I_{mp}}$ is the impulse of the gamma quantum. P_γ is the impulse received by the mass M of the atom. Everything is at a temperature of 0K, so there are no thermal phonons, at the beginning: **m = 0**. [2]

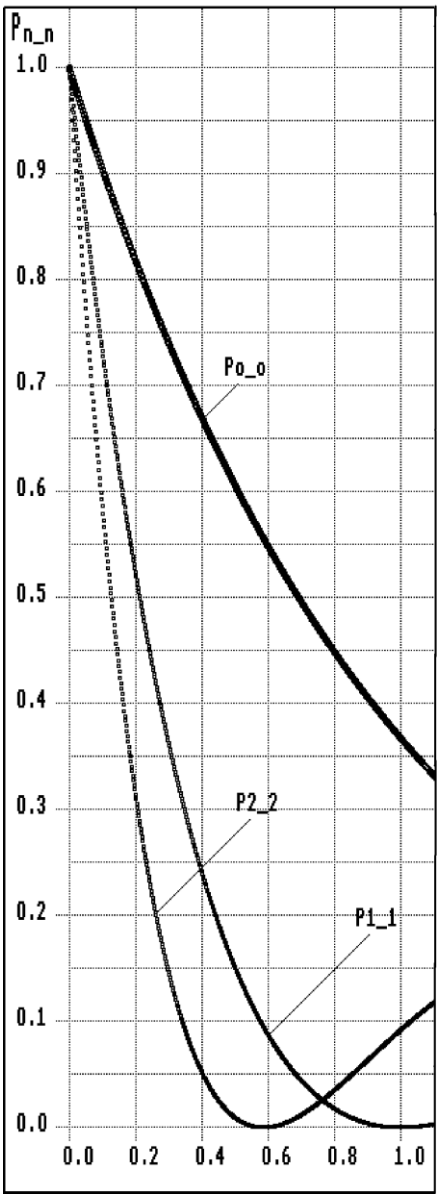

Fig. 5 Probability of no transaction for levels: 0,1, 2, versus the energy ratio $\mathcal{E} = E_c/\hbar\omega_c$. (see eq.(18))

It is well known that the vibrational density of states (DOS) forms a continuous band in bulk solids, and at low energies is well described by the Debye law.
So all the zero point phonons for all possible frequencies of the entire lattice are present simultaneously in all atoms of the lattice. In the time interval allowed by the uncertainty principle, these zero point phonons can oscillate in order to cancel an external pulse located in an atom of the lattice.
So the mass M oscillates with only one frequency. By solving [2, 3] the time dependent Schrödinger equation for the mass M, we will find that it has the Mössbauer effect that therefore already seems to be contained in the heart of Quantum Mechanics.
Our model (Fig. 4) consists of a single atom prompted by a mechanical pulse $\mathbf{I_{mp}} = \mathbf{F}x\mathbf{Dt}$, equal to the pulse $\mathbf{P_\gamma}$ of a radiated or absorbed gamma quantum. It turns out that the result has a strong analogy with the Mössbauer effect (results of numerical calculations are represented in Fig. 6a, 6b). A mass M is connected with a hypothetical rigid mass **A,** to which is linked by an elastic bond, a potential V(x), which does not depend on time. The mass M, equal to the mass of a ^{57}**Fe** atom, will have only one oscillation frequency (which corresponds approximately to the maximum frequency in a solid composed of N atoms of Fe).
$\mathbf{P_\gamma} = 0.775 \cdot 10^{-18}$ [g·cm/s] = $\mathbf{I_{mp}}$. (gamma quantum pulse)
But in the quantic world there exists another momentum that cannot be eliminated. It is originated by atoms zero point motion: $\mathbf{P_0}$ is the phonon zero point momentum (we are interested in the phonon with higher value). This momentum $\mathbf{P_0}$ can be comparable with the ***recoil momentum***: $\mathbf{P}_R = E_R / c_s$ [where $E_R = E_\gamma/(2Mc^2)$, E_R is the recoil energy, E_γ is the gamma quantum energy, M is the atom mass, c is the light velocity, c_s is the sound velocity in the lattice], but until now the momentum $\mathbf{P_0}$ is considered not at disposal to perform anything.

4 – Exact analytical solutions of the Schrödinger equation [2, 3].

The details of the analytical solution were carried out by Prof. Adriano Orefice [3].
Let us consider the case of a unidimensional harmonic oscillator of mass M, submitted to a space-independent force F(t) of arbitrary strength (Fig. 4). Such a force could represent, for instance, either a long range interaction, or a sudden absorption, emission or scattering process. The *classical* differential equation for this problem is obviously of the following form:

$$M \cdot d^2/dx^2 + k \cdot x_c = F(t) \qquad (1)$$

Exact (non-perturbative) solutions of the Schrödinger equation corresponding to the ***quantum version*** of this problem:

$$-\frac{\hbar^2}{2M}\frac{\partial^2\psi}{\partial x^2}+\left[\frac{1}{2}k x^2 - xF(t)\right]\psi = i\hbar\frac{\partial\psi}{\partial t}\ , \qquad (2)$$

were ψ(x) is the probability density. The solution of (2) was obtained almost half a century ago by Kerner [2] in a paper which did not obtain the diffusion it deserved. We shall give a somewhat modified version of such a procedure [3].

Starting from a quantum stationary state of the oscillator for F(t) = 0, its energy:

$$W_m = (m+\frac{1}{2})\hbar\,\omega_c, \quad \text{with} \quad \omega_c = \sqrt{\frac{k}{M}} \quad \text{and } \mathbf{m} = \mathbf{0},1,2,\ldots \qquad (3)$$

is assumed to be known, so that the time at which this energy has been measured is totally indetermined. The closest classical case is that of an oscillator with a known total energy $E_{TOT} = W_m$ and a completely undetermined space position within the range $\pm x_o$, with: $x_o = \sqrt{\frac{2E_{TOT}}{k}}$. The classical probability dP for the oscillator to be found in the space interval dx is given by the relation: $\frac{dP}{dx} = \frac{1}{\pi\sqrt{x_o^2 - x^2}}$ (4). In the quantum case, the possible stationary probability distributions are given by the relation:

$$\left(\frac{dP}{dx}\right)_m = N_m^2\, H_m^2(\alpha x)\ e^{-\alpha^2 x^2} \quad (m = 0,1,2\ldots) \quad (5).$$

Where:

$N_m = \sqrt{\frac{\alpha}{2^m m!\,\pi^{1/2}}}$ and $\alpha = \sqrt{\frac{M\omega_c}{\hbar}}$ (6) and the functions $\mathbf{H}_m$ are Hermite polynomials. In any case, as long as no force is applied, the center of the probability distribution ψ is placed at $x_c = 0$, with $\dot{x}_c = 0$. $dx_c/dt = 0$. Following the basic idea to "couple" the quantum solution, when an arbitrary force **F(t)** is applied, to the corresponding *classical trajectory x_c (t) of such a center,* obtained from eq.(1) we use the procedure of ref. [5]. The function $\Psi_m(x,t)$ shall be:

$$\psi_m(x,t) = N_m \exp\left\{\frac{i}{\hbar}[M\dot{x}_c\, x - \int_0^t \delta(t)\,dt - W_m t]\right\} H_m[\alpha(x-x_c)]\ \exp[-\frac{\alpha^2}{2}(x-x_c)^2] \qquad (14)$$

When the force applied F(t) is zero, the solution (14) evolves in strict association with the classical motion $x_c(t)$, whose general form is provided, for instance, in Ref.[3]. Eq.(14) shows then, in Kerner's words [2], that "*the oscillator dances a quantum dance centered at the instantaneous classical position*". The general solution (14) may be expressed in terms of the ortho-normal set of eigen-solutions of the unperturbed quantum oscillator:

$$u_n(x,t) = N_n \exp(-\frac{i}{\hbar}W_n t)\ H_n(\alpha x)\ e^{-\frac{\alpha^2}{2}x^2} \quad (n = 0,1,2\ldots) \quad (15)$$

in the form:

$$\psi_m(x,t) = \sum_{n=0}^{\infty} A_{mn}(t)\ u_n(x,t) \quad (16).$$

We have in fact:

$$A_{mn} = \int_{-\infty}^{\infty} \psi_m\, u_n^*\, dx = \frac{N_m N_n}{\alpha}\ \exp\left\{-\frac{\varepsilon(t)}{2} + \frac{i}{\hbar}\left[(W_n - W_m)\,t - \int_0^t \delta(t)\,dt + \frac{M\,x_c\dot{x}_c}{2}\right]\right\}\ G_{mn} \qquad (17)$$

where an asterisk (*) labels a complex conjugation. The term: $\varepsilon(t) = \frac{1}{\hbar\,\omega_c}\left(\frac{k\,x_c^{\,2}}{2} + \frac{M\,\dot{x}_c^{\,2}}{2}\right)$ (18) represents the total energy reached by the *classical oscillator* at the time *t*, divided by the quantum energy $\hbar\,\omega_c$. According to the solution (14) the oscillator, starting from an unperturbed stationary state ***m*** with: $x_c(t=0) = \dot{x}_c(t=0) = 0$, progressively develops, under the influence of the force F(t), the probability (assuming $n \geq m$):

$\mathbf{P_{mn}}(t) = \left|A_{mn}(t)\right|^2 = \frac{m!}{n!}\left[\varepsilon(t)\right]^{n-m}\left| \exp\left(-\frac{\varepsilon(t)}{2}\right) L_m^{\,n-m}[\varepsilon(t)] \right|^2$ (22) to be found in any state *n* (possibly, but not necessarily, coinciding with the initial one).

$\mathbf{P_{mm}}(t) = e^{-\varepsilon(t)}\left|L_m[\varepsilon(t)]\right|^2$, (23) since the *associate* Laguerre polynomial $L_m^{\,o}$ reduces to a standard Laguerre polynomial L_m.

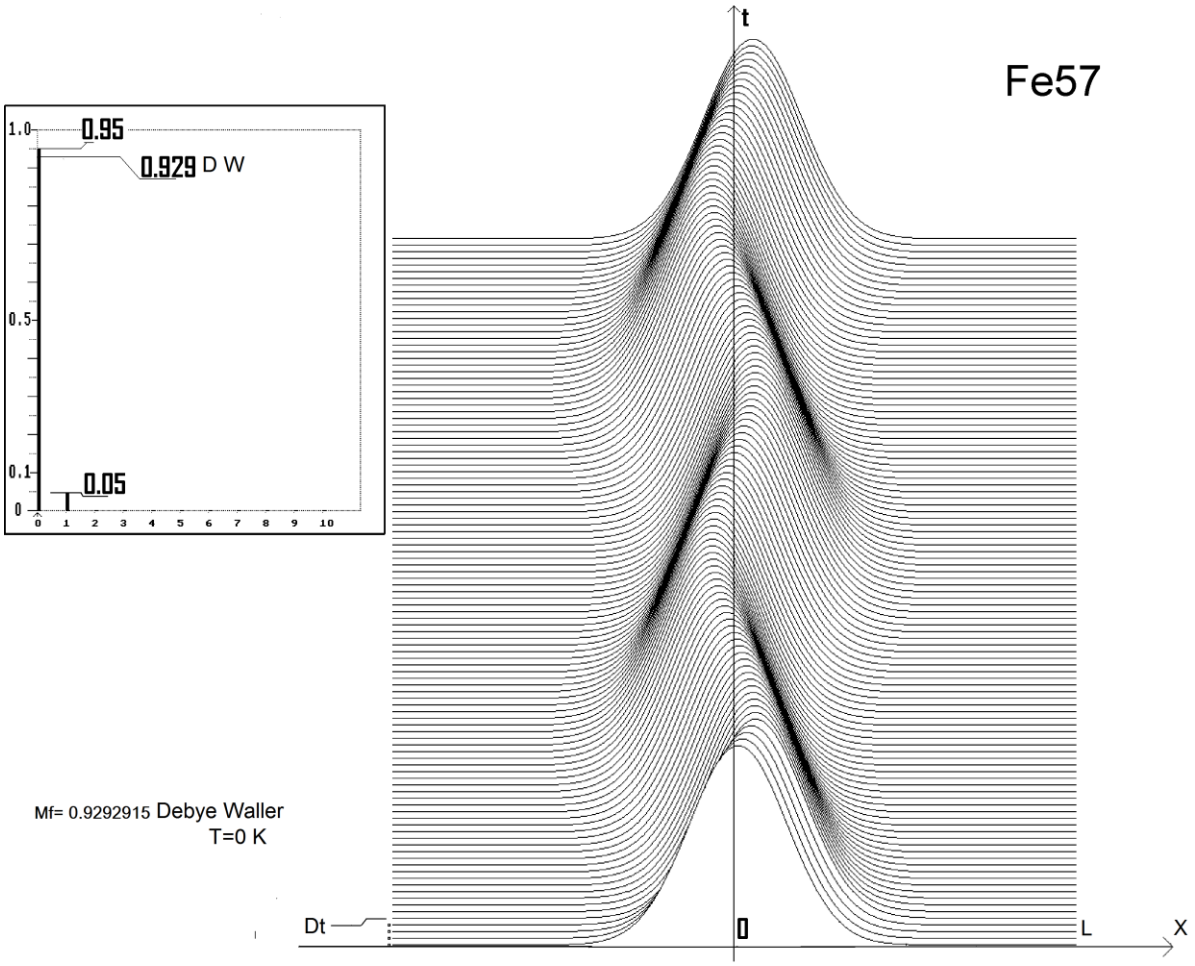

Fig.**6a**; For **^{57}Fe** probability density ψ_m during and after the pulse: **Impg** = Eg/c for **^{57}Fe** represented in the space: **L**=2,0x5.2917·10^{-9}[cm]. In insect are represnted the probabiliies (between 0 and 1) that after the pulse I_g, **n** have the vales 0,1,…10.

Sudden elastic processes undergone by a single oscillator

The general solution (14) may be applied to the particular case of an impulsive strong perturbation of a single oscillator, by assuming that a constant force **F** of arbitrary strength is exerted for

a very short time $\tau << \frac{2\pi}{\omega_c}$, as it is quite plausible in view of emission, absorption or scattering processes. The total energy, E_c, delivered to a **classical** oscillator starting from:

$x_c(t=0) = \dot{x}_c(t=0) = 0$, is given by: $E_c = \frac{(F\tau)^2}{2M}$ (24)

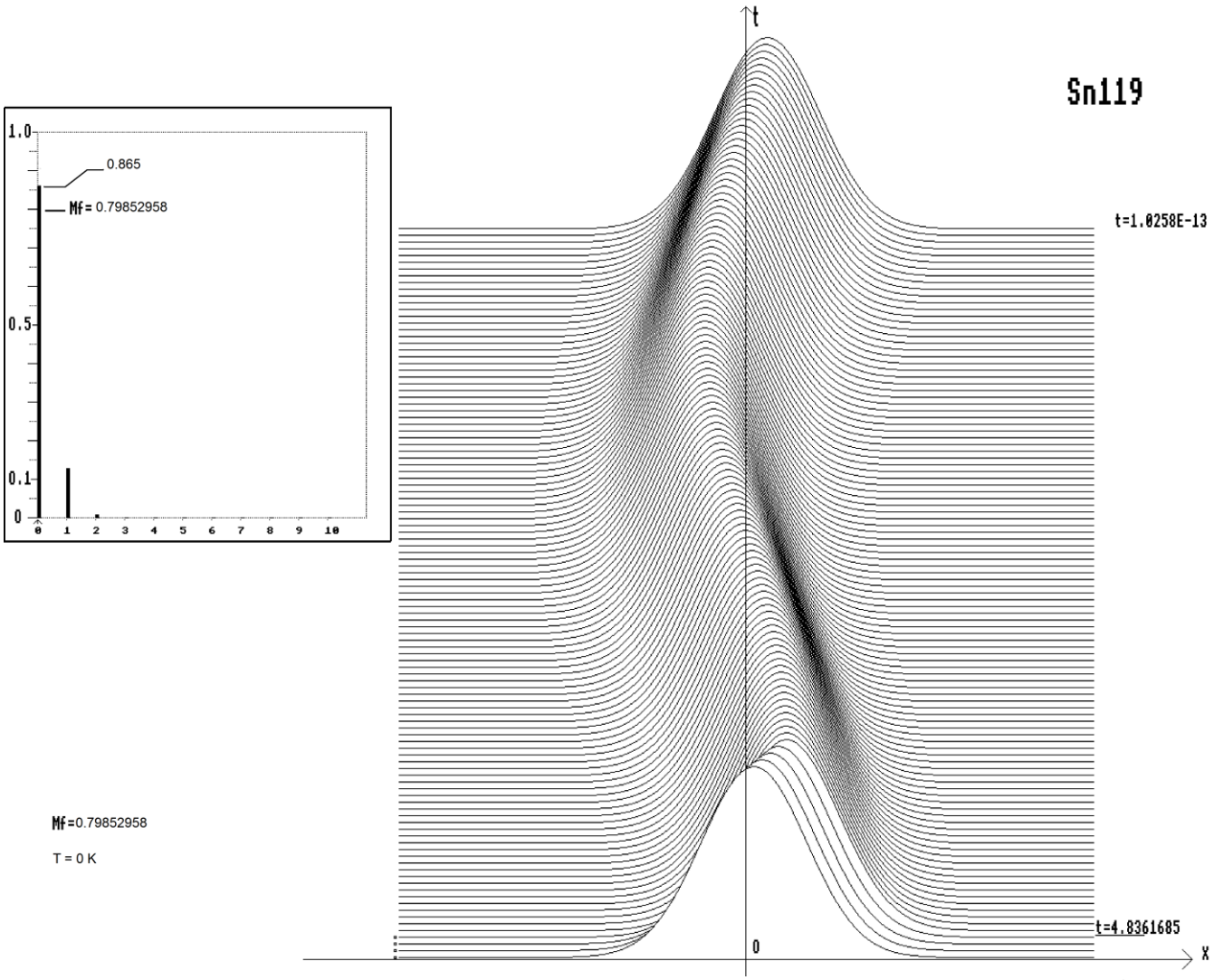

Fig. 6b. For **^{119}Sn** probability density ψ_m during and after the pulse: **Impg** = Eg/c for ^{119}Sn represented in the volume: **L**=2,0x5.2917·10^{-9}[cm]; t = 4.8361685x2.41884·10^{-17} =1.16979·10^{-16}[s]

Assuming, for simplicity sake, that the oscillator, submitted to such a shock, has no time to substantially change its initial position $x_c = 0$, we may employ the solution (14) with:

$x_c(t) = \sqrt{\frac{2E_C}{k}} \sin\omega_c t$ (25), $\dot{x}_c(t) = \sqrt{\frac{2E_C}{M}} \cos\omega_c t$ (26), $\int_o^t \delta(t)\,dt = \frac{E_C}{2\omega_c} \sin 2\omega_c t$, (27)

and make use of the transition probability (22) with: $\varepsilon = \frac{E_C}{\hbar\omega_c}$. The effect of the shock is that of causing a classically oscillating probability distribution, as was also accounted (in the limited case of $m = 0$) by Schiff [6]. Such an oscillating distribution is a superposition of all the stationary states of the unperturbed oscillator. The probability, in particular, for the oscillator to remain in its

initial state *m* is obtained from eq.(23) in the for $P_{mm} = \exp(-\frac{E_C}{\hbar\omega_c}) \left| L_m(\frac{E_C}{\hbar\omega_c}) \right|^2$, (28) By plotting P_{mm} versus $\varepsilon \equiv \frac{E_C}{\hbar\omega_c}$ it may be verified that it exhibits, for $\varepsilon > 1$, *m* not negligible maxima, shown in **Fig. 5**, which no perturbative approach (with $\varepsilon << 1$) may predict, although values of **ε** even much greater than unity are currently encountered in the family of elastic processes we are considering here.

$$\psi_m(x,t) = N_m \exp\left\{\frac{i}{\hbar}[M\dot{x}_c\, x - \int_0^t \delta(t)\, dt - W_m t]\right\} H_m[\alpha(x - x_c)]\ \exp[-\frac{\alpha^2}{2}(x - x_c)^2] \quad (14)$$

From [7] the probability **f** that Mössbauer effect occurs is:
f ≈ $\exp[-3E_R/(2k_B\cdot\theta)(1+2\cdot(\pi\mathbf{T}/\theta)^2/3)]$,
Where **θ** is the Debye temperature. For T=0 becomes: f ≈ $\exp[-3\mathbf{E_R}/(2k_B\cdot\theta)]$ **= Mf,** that is reported in Fig. 6a, 6b.

In the Debye model and at zero degree Kelvin temperature, the recoil free fraction is given by: $DW_{T=0K} \approx \exp[-E_R \times 3/2]$. This is indicated in Fig.6a, 6b as **Wf**

5 - Zero point phonons: energy and momentum

This model (Fig. 4) shows a "stiffness" slightly higher than that predicted by the Debye-Waller theory applied to a solid (bulk), for which **f** = DW = 0.929, (at zero K) while from the calculation with the model of Fig. 4 with a single atom we have: DW = 0.95. This model is not physically feasible but reveals that a single atom, with a single oscillation frequency, bound by a potential V(x), which does not depend on time, has the Mössbauer effect. In reality, every atom that emits or absorbs a gamma quantum in a lattice is bound to a potential that is also a function of time: V(r, t). The propagation of the anchoring of the potential would obviously proceed with "acoustic" speed in such long times that the time dependence of the potential V is irrelevant.
Another problem arises when the solid, which should anchor the atom that absorbs the gamma quantum, is a nanoparticle, which should recoil, with an effect strong enough to be detected in the same Mössbauer spectrum. (see **Part 1**)
In the model adopted in our calculation (Fig. 4), the atom (with mass M), hit by a pulse $\mathbf{I_{mp}}$, is bound to a very large mass **A**, which with the Mössbauer effect not only does not absorb energy in vibrational levels (phonons created are the same envisaged by the Debye-Waller formula) but neither seems to recoil if in place of mass A we have the mass of a nanoparticle.. Seems that the nanoparticle does not receive translational energy.
The whole nanoparticle does not even seem to recoil as a whole.
In Fig. 4 we see a single atom, elastically bonded to a large mass A and we can only ascertain that at 0 K (results in Fig. 6a, 6b) we have probability 1 for n=0, the

other n= 1, 2, 3 are zero) before apply the gamma pulse. After the pulse is applied we represents the numerical calculation result.
We do not know what happens if the mass A, to which it is anchored (elastically) the single atom, is not large enough to cancel the recoil. The "rigidity", already present in the solutions of the Schrödinger equation, is seen to arise a rigidity that even leads to the disappearance of the recoil. [8]
The analysis, carried out on the single atom model, leads to the result that the Mössbauer effect occurs also with a single atom which is the seat of a single zero point phonon. So the Mössbauer effect is already described by the time dependent Schrödinger equation. The conclusion is:
the Mössbauer effect derives exclusively from the phonons "parked" in the same atom of the lattice in which the effect occurs.
The highest probability of not creating phonons is P_{0_0} (Fig. 5). Even for phonons with n> 0, for low energy transfer (**ε**), there is a non-zero probability that a transition occurs that does not create thermal phonons (Pn_n >0).
The recoil of the entire nanoparticle can be covered by the Heisenberg uncertainty time. The existence of the Mössbauer effect, even in nanoparticles with a mass lower than that necessary to mask the recoil (see **Part 1**), as already mentioned, removes any validity from any theory based on the "solidarity" of the whole lattice around the atom that undergoes a "mechanical impulse" either by emission or absorption of a gamma quantum.

6 - Zero point momentum and energy for a single oscillator

All oscillators, in the quantum description, have a zero point energy. In very fast transient phenomena, zero point energy can occur in the time intervals covered by the uncertainty principle. For a single oscillator, the energy E is:

$$E=\omega\cdot\hbar\cdot(n+\tfrac{1}{2}), \qquad (29)$$

The density of states is: $\rho(\omega) = B\ (\omega^2/\ \omega^3_D)$
where **n** is the average number of (thermal) phonons present. **n** depends on the temperature, while the angular frequency ω is the maximum frequency typical of the single classical oscillator and applies: $\omega = (k/m)^{1/2}$. For a single, isolated oscillator we have only one angular frequency ω. The number **n** of phonons (from [2]) be present in the oscillator for the frequency ω is given by:

$$n(\omega,T) = 1/(e^{(\hbar\omega/KT)} -1) \qquad (30),$$ where K is the Boltzmann constant. For $T\rightarrow 0$: $n\rightarrow 0$

$E_{j,\ T=0} = \omega_j\cdot\hbar\cdot(\tfrac{1}{2})$, energy of quantum oscillator.

This quantum model applies to any oscillation in the atomic field. It is valid both for the oscillations that involve the atom in the lattice and for the oscillations inside the

atom up to those inside the nucleus. In particular, for a lattice of N atoms, N-1 different oscillations are possible, with different frequencies, from the lowest ones that involve the far atoms, up to the highest ones involving only 2 contiguous atoms. In this case the vibration energy of the i-th atom will be given by the sum of all N-1 possible frequencies:

$$E_i = \sum_{j=1}^{j=N-1} \omega_j \cdot \hbar \cdot (n_j(\omega_j,T) + ½) \qquad (31)$$

The total vibrational energy E_t of the lattice is given by the sum of the energy of the i-th atom, where all the zero-point N -1 oscillations (phonons) are present:

$E_{0,i} = \sum_{(j=2,\ldots N-1)} [\omega_j \cdot \hbar \cdot (½)]$ energy of N - 1 zero-point phonons

$$E_t = \sum_{(i=1,\ldots N-1)} E_{0,i} \qquad (32)$$

Thus each lattice atom will accommodate all N zero point oscillations at all the lattice frequencies ω_j. For temperatures below the temperature of Debye we will have a region where the zero point energy is higher than that due to the (thermal) phonons

For Yong Yang et al.: "*Characterization of Zero-point Vibration in One-Component Crystals"* [10] the magnitude of zero-point vibration in one-component crystals, whose constituent atoms share the same bonding geometry, prove the existence of a characteristic temperature, T_0, at which the magnitude of zero-point vibrations equals to that of the excited vibrations. Within the Debye model T_0 is found to be ~1/3 of the Debye temperature. The results are demonstrated in realistic systems.

$T_0 \approx T_D \cdot 1/3$.

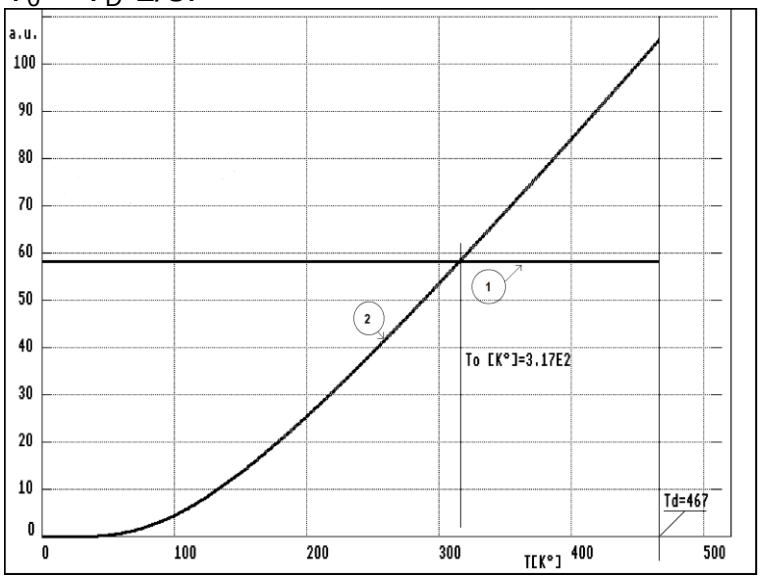

Fig. **7.** At 317 Kelvin degree thermic phonons energy is equal to energy of zero point phonons for ^{57}Fe.

$T_0 \approx T_d$ (2/3) [10] Vertical arbitrary units. E_0 zero point energy = 58.3. Debye temperature **T_D = 467** [°K]. (1) is the constant diagram of zero point phonons (eq.31). (**2**) is the diagram of thermal phonons (eq.30). For the crystals whose constituent atoms share the same bonding geometry, was proved the existence of a characteristic temperature, T_0, at which the magnitude of zero-point vibrations equals to that of the excited vibrations by thermal phonons. Within the Debye model T_0 is found to be ~1/3 of the Debye temperature **T_D**. The results are demonstrated in realistic systems [10].

"*…exists a characteristic temperature T_0, at which the mean square displacement (MSD) of zero-point and excited vibrations has equal magnitude. Below T_0 the zero-point vibration is dominant over the excited vibrations. Within the Debye model, we obtain a simple relation between T_0 and the Debye temperature.*"

About the relevance of zero-point phonons it is interesting to read: "*Characterization of Zero-point Vibration in One-Component Crystals*"[10], that show the magnitude of zero-point vibration in one-component crystals. For the crystals whose constituent atoms share the same bonding geometry, we prove the existence of a characteristic temperature, $\mathbf{T_0}$, at which the magnitude of zero-point vibrations displacement equals to that of the excited vibrations. Within the Debye model $\mathbf{T_0}$ is found to be ~1/3 of the Debye temperature $\mathbf{T_D}$.

7) The Heisenberg uncertainty

The attempt to invoke the Heisenberg uncertainty principle to give an explanation of the Mössbauer effect has rarely been made. An attempt at explanation in this direction was tempted by H.-D. Pfannes et al. [9]. But the conclusions are unclear: «The Mössbauer effect is based on the "recoilless" absorption and emission of low energy (E_0=10÷100 keV) gamma-photons in solids. ***A simple explanation for this effect relies on the Heisenberg uncertainty relation:*** the uncertainty in momentum of bound atoms is: $\Delta p \geq \hbar/\Delta x$. Where uncertainty in momentum Dp is of the order of 10^{-23} [kg·m·s^{-1}]. The uncertainty in position is Dx (Δx = 0.1 Å) but the recoil moment of e.g. a gamma photon with energy E_0=10 [keV] is smaller ($\Delta p \geq 5\cdot10^{-24}$ [kg·m·s^{-1}]), i.e. the recoil which eventually can excite vibrations (phonons) of the emitting atom sometimes may not be measurable.» Pfannes [9] continues, following the current theory, saying: «*The recoil is then transmitted to the crystal as a whole and since the mass of the crystal is much greater than the atomic mass it does not alter the gamma-energy ("recoilless" emission). … when the lifetime **t** of the excited Mössbauer energy level is longer (e.g. **t** = 10^{-7}s) than a period T of vibration (phonon) frequency of the emitting or absorbing atom (e.g.10^{-13}s). The atom carries out many cycles during the lifetime of the gamma photon and the Doppler broadening of the emitted radiation averages out. As a result a sharp line with the natural linewidth G = ħ/**t** at the position E_0 is emitted from the source and nuclear resonance absorption with an energetic resolution $G/E_0 = 10^{-13}$, sufficient to resolve hyperfine interactions, is possible. The above mentioned conditions for recoilless emission limits the Mössbauer isotopes to those isotopes which possess low energy nuclear g-transitions (small recoil moment), long lifetimes of the excited state (hyperfine resolution), high Debye temperature (small Dx) and solid sources and absorbers.*»

From this new theory we have instead: the Heinsenberg uncertainty principle enters the physical nature of the phenomenon by providing a time interval (a "*cover*" of time) $\Delta t \geq 3.29\cdot10^{-14}$ [s]) for the phenomena of emission or absorption without the creation of phonons. In the following we employ ^{57}Fe.
The recoil momentum can be stopped by high energy phonons "parked" in the atom where Mössbauer effect happens

$\mathbf{E_\gamma} = 1.44\cdot10^{4}$ [eV] $= 2.307\cdot10^{-8}$ [erg]: Energy of gamma quantum

From the uncertainty principle:

$\Delta p\cdot\Delta x \geq \hbar/2$; $\Delta E\cdot\Delta t \geq \hbar/2$; $\Delta t \geq (\hbar/2)/\Delta E$

$\mathbf{\Delta E = E_R}$ - The recoil energy must be "missed". With the period T_D of an oscillation of the highest energy zero-point phonons:

$T_D = 2\pi/\omega_D = 1.14\cdot10^{-13}$ [s]; Debye period where ω_D is the Debye frequency: $\mathbf{\omega_D} = K_B\cdot T_D/\hbar \approx 5.5\cdot10^{13}$ [rad/s]; Debye frequency

$\mathbf{\Delta E = E_R} = E^2_g/(2M_{Fe}\cdot c^2) \approx 2\cdot10^{-3}$[eV] $= 3.204\cdot10^{-15}$[erg];

$\mathbf{\Delta t} \geq (\hbar/2)/E_R = 5.2727\cdot10^{-28}/3.204\cdot10^{-15} = 1.6456\cdot10^{-13}$[s]

The maximum energy of zero point phonons is given by:

$E_{\omega\text{-max}} = \hbar\cdot\omega_D/2 = 1.055\cdot10^{-27}\cdot6.11\cdot10^{13}/2 = 3.223\cdot10^{-14}$ [erg]

$E_\gamma >> E_{\omega\text{-max}}$;

On the contrary the momentum of the high energy phonons $\mathbf{P_\omega}$ and the momentum of gamma photon Pγ, are comparable:

$c_s \approx 5.1\cdot10^{5}$ [cm/s]

$P_\omega = \mathbf{E_\omega/c_s} = 6.32\cdot10^{-20}$ [g·cm/s], where c_s is the sound velocity :

$P_\gamma = E_\gamma/c = 7.75\cdot10^{-19}$ [g·cm/s], where c is the light velocity

$\mathbf{P_\omega < P_\gamma}$

Recoil momentum P_R

$\mathbf{P_R \approx E_R}/c_s = 3.204\cdot10^{-15}/5.1\cdot10^{5} = 6.282\cdot10^{-21}$ [g·cm/s]

$P_\omega >> P_R$; this confrontation is wright because P_ω the impulse of the zero point oscillations is greater than that of recoil that is transferred from the gamma quanta to the atom. The gamma quantum with energy Eγ was absorbed (or emitted) by the nucleus. At the moment of absorption (or emission), the recoil movement of the same atom can be canceled by the zero point phonons with higher moment. To achieve this, it is necessary to eliminate the mechanical recoil energy. E_R. This can happen mainly thanks to the momentum of the zero point phonons. At the moment of absorption (or emission) of gamma quantum **Eγ**, to cancel the mechanical recoil, that propagates with the speed of sound c_s, all the movement of the atom must be canceled. Therefore only the mechanical recoil energy must be eliminated thanks to the momentum of the zero-point phonons: $P_\omega > P_R$.

To verify the uncertainty concerning the recoil:

$\Delta E \cdot \Delta t \geq \hbar/2$; where: $\Delta E = E_R$

$\Delta t \geq (\hbar/2)/E_R$; Time period at maximum frequency: $T=1.14\cdot10^{-13}$ [s]

$\Delta t \geq 5.2727\cdot10^{-28}/\ 1.602\cdot10^{-14} = 0.329\cdot10^{-13}$[s]; $\Delta t<T$

But Δt and T are comparable. We provide two clues:

a) ***the momentum of the gamma photon recoil can be "stopped" locally by the momentum of zero point phonons. The whole event takes place within the time interval*** Δt ***covered by the uncertainty. The spontaneous intervention of zero-point phonons is a new phenomenon to be analyzed.***

b) ***After the gamma photon has been emitted (or absorbed), the distribution of the zero-point phonons is re-established in a time covered by the uncertainty principle.***

Emission and absorption occur with the "immobilized" atoms in a short time interval, with the result that no localized creation of phonons occurs.

At this point it was a matter of conjecture that was denied by an experimental fact: no recoil even for particles (nano crystals) that do not have sufficient mass to absorb the recoil (Part 1). This annuls all hypotheses about the participation of a large number of lattice atoms to absorb the recoil energy. The main fact is that experimentally the recoil has never been seen, however small the crystal was.

A gamma photon, whose energy is close to that of absorption by resonance, must have a supplement of energy equal to the recoil that the atom will undergo. A photon that has exactly the same energy as the resonant must meet a "blocked" atom

so that it does not have to lose the E_R energy, which would send it out of the resonance. To realize this "block" it is necessary to cancel the recoil ***before*** it is formed. A sort of temporal inversion should be created that is possible within quantum mechanics, in the time interval allowed by the uncertainty principle. If the momentum associated with the energy E_R is not too high it can be canceled by zero-point phonons. During the time Δt a mechanical action is necessary to maintain the atom in its original position. A pulse must be available in an extremely short time to block the recoil, but during this time, for the Heisenberg uncertainty principle, we cannot know what really is happening.
The recoil is not canceled but occurs in the indetermination time interval Δt and therefore does not appear in the energy balance of irradiation and absorption of the gamma quantum. The recoil occurs after the "elastic" phenomenon has occurred. Therefore the quantum elastic phenomena would be the result of the temporal coverage given by the uncertainty principle.

It remains to be discovered who absorbs, even temporarily, the momentum of the incoming particle or gamma quantum.
The most plausible hypothesis is that the recoil is canceled by the momentum of the zero point oscillations (zero point phonons) *for the natural tendency to maintain the initial conditions*. Thus the oscillation impressed to the atom by the recoil would be stopped by the momentum of the zero point oscillations. This causes a temporary imbalance in these oscillations, an imbalance that disappears in the interval of time allowed by the uncertainty.

8) - CONCLUSION

Until now exists *A Mysterious Consequence of Mössbauer's Effect* [11].The Mössbauer effect is a phenomenon localized in atoms whose nuclei radiate or absorb a quantum of gamma radiation. In fact, in the gamma absorption spectra, only information concerning that same single atom and nucleus appears. No evidence exists of a sudden solidarity of the atoms of the lattice. The solidarity, however, is impossible due to lack of time. But there is another reality: the zero point phonons. These phonons are present in every atom. This model has been criticized for suspicion of divergence in the number of phonons by Gründler [4], a number that would tend to infinity for a very large solid. However, as far as the Mossbauer effect is concerned, this is a false problem. Only phonons with high momentum are of interest, those that concern phonons with a small wavelength and involve the atoms closest to the atom concerned. The possibility remains that the momentum of the zero point phonons can compensate and cancel the momentum of the recoil of atom hit by gamma quantum emitted or absorbed.

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