Title: Is the emergence of macroscopic behavior due to a quantum mechanical indeterminacy of the structure of the Einsteinian Space-Time?

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Abstract: According to a widely accepted view, the emergence of macroscopic behavior is related to the loss of quantum mechanical coherence. Opinions on the possible cause of this loss diverge. In the present talk it will be shown how a small, assessable amount of indeterminacy in the structure of space-time may lead to the emergence of macroscopic behavior, in agreement with empirical evidence.

Is the Emergence of Macroscopic Behavior due to a Quantum Mechanical Indeterminacy of the Einsteinian Space-time Structure ? 1

Károlyházy (1964-72)

Cell length a_c of a single microparticle

$$a_c \approx \left(\frac{L}{\Lambda}\right)^2 L \qquad \left(L = \frac{\hbar}{cM}\right)$$

$\frac{1}{e}\left(\frac{2}{3}\right)$

Is the Emergence of Macroscopic Behavior due to a Quantum Mechanical Indeterminacy of the Einsteinian Space-time Structure? 1

Is the Emergence of Macroscopic Behavior due to a Quantum Mechanical Indeterminacy of the Einsteinian Space-time Structure? 1

Subtitles:

2. A Compromise between Quantum Mechanics and General Relativity

3. Lower Bound of the Indeterminacy in the Length of a Time Interval, and in the Synchronization of Moments of Time

4. A Tentative Expression of $(\Delta_L T)_{sym}$ through Vacuum Expectation Values

5. Indeterminacy in the Relative Phases of a Quantum State

6. The Coherence Cell and the Cell Length of a Single Microparticle

7. The Coherence Cell and the Cell Length of Homogeneous, Spherical Solid Bodies

8. The Transition from Quantum (micro) to Classical (Macro) Behavior

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- Taking into Account the Surroundings

- Submacroscopic Decay of a Superposition in a Gas
- A Remark on Superconductivity
- Anomalous Brownian Motion
- Smoothing the jumps (GRW)
- Comment on the Non-Choice of a Preferred Basis

15. Concluding Remark

2. A Compomise Between

GR

$\Delta x \cdot \Delta p \geq \frac{\hbar}{2}$ → Δ in the structure of space-time → $\Delta_\phi(x, x', t)$

$\phi(x, x', t) = \varphi(x', t) - \varphi(x, t)$

in the Ψ of any physical system.

$x = (\underline{x}_1, \ldots, \underline{x}_N)$

N: number of microparticles constituting the system

If $\Delta_\phi(x, x', t) \geq \pi$, the coherence between x' and x is lost.

Massive bodies influenced strongly, microparticles weakly

When the Ψ of a massive body expands in the course of its Schrödinger time evolution, non-overlapping, incoherent domains begin to appear in the configuration space. Károlyházy <u>assumed</u> that if this happens, then

Ψ stochastically localizes itself to one of the domains inside which $\Delta\phi \leq \pi$, thereby counterbalancing the deterioration of its coherence. From that domain Ψ expands again as dictated by the Schrödinger equation, until the deterioration of its coherence calls for the next self-localization, and so on.

A stochastic self-localization triggered by the appearence of [illegible] overlapping incoherent domains [illegible] to a breakdown of the superp[illegible] principle independently of [illegible] tion. This is a non-uni[illegible] component of the ti[illegible] as objective as [illegible] istic Schrödinger[illegible]

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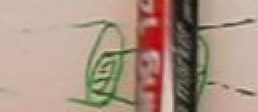

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$\Delta\phi \lesssim \pi$,

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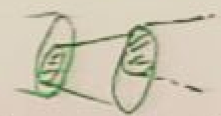

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This is how QM and GR seem to cooperate to preserve the coherence of the ψ's of the microparticles, and to prevent the excessive expansion of the ψ's of macroscopic bodies. By the same token the development of large indeterminacies in the space-time structure is also prevented. This balance is reached by giving up the perfect sharpness of the structure of space-time in GR, and the absolute v[illegible] of the superposition principle [illegible].

3. Lower Bo[illegible] Indeterminacy in the [illegible]e Interval and in [illegible] of Moments of Ti[illegible]

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3. Lower Bound of the Indeterminacy in the Length of a Time Interval and in the Synchronization of Moments of Time

Studying the relations between the indeterminacies induced by a QM-al object put into an otherwise classically empty (Minkowskian) space-time, K. noticed the existence of a lower bound of the indeterminacy of the Einsteinian space-time structure. The order of magnitude of this bound could be estimated, and conveniently expressed in the form of a relation between the le T of a time interval, and the smallest ible value $\Delta_L T$ of the indeterminacy of T " stands for "Lower bound".)

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Namely, it turns out that

$$\Delta_2 T \approx T_P^{2/3} T^{1/3}, \qquad * (a)$$

where

$$T_P = 5.4 \times 10^{-44} \text{ sec}$$

is the Planck time.

$\approx \rightarrow$ Equal, up to a numerical constant of order 1, possibly 10. Cannot be calculated at present. Fortunately not important in what follows.

Salient point in the deduction of $*$:
A quantum object induces indeterminacy not only through Δx, but through Δp, too, and Δx and Δp work against each other; $\Delta x \cdot \Delta p \geq \hbar/2$.

Two restrictions on T:

i) Non-relativistic QM $\rightarrow$
$\rightarrow$ T along $|\underline{v}| \ll c$ worldlines
(in a frame in which 2.7°K isotropic)

ii) $T \gg T_P$,

because for $T \lesssim T_P$ the concept of the space-time structure is questionable.

$*$ QM-al, not field theoretical!

Notice that

- for given T, $\Delta_L T$ is an absolute lower bound. (compare with $\Delta x \cdot \Delta p \geq \hbar/2$)

- $\Delta_L T$ is very small. E.g. for $T = 1$ sec

$$\Delta_L T \approx 10^{-29} \text{ sec.}$$

Still, $\Delta_L T$ is large enough to harm the coherence of the Ψ's of bodies perceived empirically macroscopic ("classic"), and small enough the leave the coherence of the Ψ's of microparticles nearly perfect.

A remark on $*$:

$*$ involves only the universal constant(s)

$$= \left(\frac{G\hbar}{c^5}\right)^{1/2},$$

... constant of gravitation. The ... (mass, velocity) of the quantum ... deduction of $*$ dropped out.

$\Delta_L T \approx t_P$!

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$$T_P = \left(\frac{G\hbar}{c^5}\right)^{1/2},$$

where G is the constant of gravitation. The physical parameters (mass, velocity) of the quantum object used in the deduction of $*$ dropped out.

A space-time relation independent of any particular property of matter can be, perhaps even must be attributed to space-time itself. We know that the expectation concerning the simplicity of ground states, or "vacuums", had to be given up in the quantum world. Examples are the zero point energy of the oscillator, the Dirac sea, the vacuum of the electro-weak interaction.

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[illegible]e lower bound $\Delta_L T$ of [illegible] the length of time intervals [illegible] worldlines involves the [illegible]wer bound $(\Delta_L T)_{syn}$ of [illegible] the syncronization of the [illegible]wo such worldlines.

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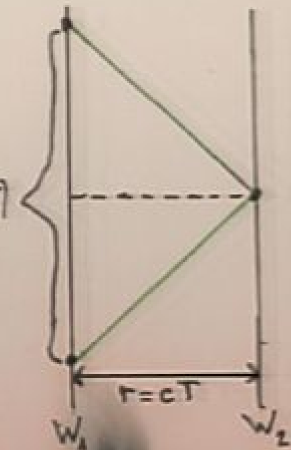
\# says that the compatibility of GR with QM demands, as a minimum, that the structure of the empty space-time had a slight indeterminacy, therefore it cannot be exactly Minkowskian. A deeper understanding of this property probably cannot be reached without a unified theory of Quantum Physics and General Relativity.

The existence of the lower bound $\Delta_L T$ of the indeterminacy in the length of time intervals along the $|\underline{v}| \ll c$ worldlines involves the existence of a lower bound $(\Delta_L T)_{syn}$ of the indeterminacy in the syncronization of the moments of time on two such worldlines.

Consider, first in Minkowskian space-time, two $|\underline{v}|=0$ worldlines W_1 and W_2 at a distance r each other. A light signal emitted on W_1 arrives back to W_1 from W_2 after a time $2T$, where

$$T = \frac{r}{c}.$$



The time interval along W_1 has the indeterminacy

$$\Delta_L(2T) \approx \Delta_L T,$$

therefore the moment of the arrival of the signal to W_2 cannot be synchronized with a corresponding moment on W_1 better than with the indeterminacy

$$(\Delta_L T)_{syn} \approx T_P^{2/3}\left(\frac{r}{c}\right)^{1/3} = \frac{\Lambda^{2/3}\, r^{1/3}}{c},$$ ✱✱

where

$$\Lambda = c\,T_P = 1.6 \times 10^{-33}\ \text{cm}$$

is the Plank length.

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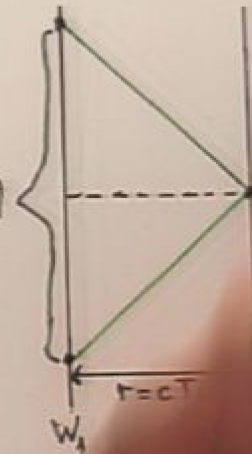

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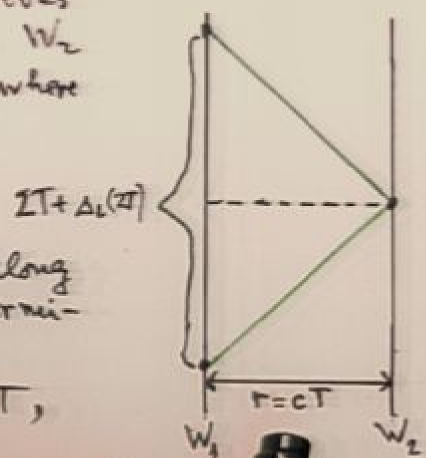

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Sc- ... y to $\Delta_L T$, $(\Delta_L T)_{syn}$ is an attribute of the space-time structure, therefore it cannot be beaten by clocks, however exact. Notice that $(\Delta_L T)_{syn}$ is small. The relative lower bound

$$\frac{(\Delta_L T)_{syn}}{r/c} \approx \left(\frac{\Lambda}{r}\right)^{2/3} \xrightarrow[r\to\infty]{} 0,$$

and for $r = 10$ meter (T ... $= 10^{-8}$sec) it is already as small as 10 ...

4. A Tentative Expression for $(\Delta_L T)_{syn}$ (and for $\Delta_L T$) through Vacuum Expectation Values

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4. A Tentative [illegible]xpression for $(\Delta_L T)_{syn}$ (and for Δ_L[illegible] through Vacuum Expectation Values[illegible]

In the future [illegible]unified theory of QM and GR, the indeterm[illegible]acies $\Delta_L T$ and $(\Delta_L T)_{syn}$ will presumabl[illegible]pear as spreads in the ground stat[illegible] time. An expression for $(\Delta_L T)$[illegible] nerel[illegible]e directly to the ge- ginal[illegible] for $\Delta\phi$ than the ori- as[illegible] can be obtained attribute of the space-time structure, therefore it cannot be beaten by clocks, however exact. Notice that $(\Delta_L T)_{syn}$ is small. The relative lower bound

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In the future unified theory of QM and GR, the indeterminacies $\Delta_L T$ and $(\Delta_L T)_{syn}$ will presumably appear as spreads in the ground state of space-time. An expression for $(\Delta_L T)_{syn}$, leading more directly to the general formula of K for $\Delta\phi$ than the original deduction (1972), can be obtained as follows:

Similarly to $\Delta_L T$, $(\Delta_L T)_{syn}$ is an attribute of the space-time structure, therefore it cannot be beaten by clocks, however exact. Notice that $(\Delta_L T)_{syn}$ is small. The relative lower bound

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In the future unified theory of QM and GR, the indeterminacies $\Delta_L T$ and $(\Delta_L T)_{syn}$ will presumably appear as spreads in the ground state of space-time. An expression for $(\Delta_L T)_{syn}$, leading more directly to the general formula of K for $\Delta\phi$ than the original deduction (1972), can be obtained as follows:

Consider a t = constant hyperplane in Minkowskian space-time. For any pair of points $\underline{x}$, $\underline{x}'$ on such a plane

$$t_{\underline{x}'} = t_{\underline{x}} = $$

that is

$$t_{\underline{x}'} - t_{\underline{x}} = 0 \qquad (a)$$

In a space-time

$$(\Delta$$

'$t_{\underline{x}'}$ - ... inacy. It seems ... that its ver ... ro value,

and i ... $T)^2_{syn}$:

$$\langle (t ...)^2_{syn} \simeq \frac{\lambda^{4/3}}{c^2} |\underline{x}' - \underline{x}|^{2/3}.$$

(An ex ... btained in a similar ... led in this talk.)

(a)

In a space-time where

$$(\Delta_L T)_{syn} \neq 0,$$

$t_{\underline{x}'} - t_{\underline{x}}$ is an indeterminacy. It seems reasonable to assume that its vev equals the Minkowskian zero value,

$$< t_{\underline{x}'} - t_{\underline{x}} > = 0,$$

and its squared spread equals $(\Delta_L T)^2_{syn}$:

$$< (t_{\underline{x}'} - t_{\underline{x}} - < t_{\underline{x}'} - t_{\underline{x}} >)^2 > = (\Delta_L T)^2_{syn} \simeq \frac{\Lambda^{4/3}}{c^2} |\underline{x}' - \underline{x}|^{2/3}.$$

(An expression for $(\Delta_L T)^2$ can be obtained in a similar way, but it is not needed in this talk.)

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(An expression for $(\Delta_L T)^2$ can be obtained in a similar way, but it is not needed in this talk.)

then $\phi(t) \to \phi(x,t) = -\frac{c^2}{\hbar}\sum_{\ell=1}^{N} M_\ell t_{\underline{x}_\ell}$,

because the [illegible] ordinate of the particle with mass M_ℓ is $\underline{x}_\ell$. The [illegible] lative rest energy phase between x and x' [illegible]

$$\phi(x,x',t) [illegible] \phi(x',t) - \phi(x,t)$$

$$= - [illegible] \sum_{\ell=1}^{N} M_\ell (t_{\underline{x}'_\ell} - t_{\underline{x}_\ell})$$

Remark: [illegible] is not clear what kind of a substitution [illegible] made for t in the

[illegible] $\to$?

phas[illegible] non-relativistic

c[illegible]

[illegible] ntribution comes [illegible] ase factor.

[illegible] 0,

[illegible] 0,

[illegible] $x',t) - 0)^2 \rangle =$

[illegible] $- t_{\underline{x}_i})(t_{\underline{x}'_\ell} - t_{\underline{x}_\ell})\rangle$.

cribed by

$$\Psi(x,t) = e^{-\frac{i}{\hbar}Ht}\,\Psi(x,0).$$

... Minkowskian space-time the evolution is deterministic, the relative phases between any pairs of points

$$x = (\underline{x}_1, \ldots, \underline{x}_N)$$

and

$$x' = (\underline{x}'_1, \ldots, \underline{x}'_N)$$

of the configuration space are sharply determined; Ψ is and remains perfectly coherent.

How does ** affect the relative phases?

The main influence shows up in the usually omitted rest energy phase factor

$$e^{-\frac{i}{\hbar}\sum_{\ell=1}^{N} M_\ell c^2 t} := e^{i\phi(t)}$$

(Omitted because it is independent of x and of $p = -i\hbar(\nabla_1, \ldots, \nabla_N)$, drops out)

But if $t_{\underline{x}'} \neq t_{\underline{x}}$

then ...

In the time evolution of an isolated system of N microparticles is described by

$$\Psi(x,t) = e^{-\frac{i}{\hbar}Ht}\,\Psi(x,0).$$

On the Minkowskian space-time the evolution is deterministic, the relative phases between any pairs of points

$$x = (\underline{x}_1, \dots, \underline{x}_N)$$

and

$$x' = (\underline{x}'_1, \dots, \underline{x}'_N)$$

of the configuration space are sharply determined, i.e. Ψ is and remains perfectly coherent.

How does ** affect the relative phases?

The main influence shows up in the usually omitted rest energy phase factor

$$e^{-\frac{i}{\hbar}\sum_{l=1}^{N} M_l c^2 t} := e^{i\phi(t)}$$

(Omitted because it is independent of x and of $p = -i\hbar(\nabla_1, \dots, \nabla_N)$, drops out)

But if

$$t_{\underline{x}'} \neq t_{\underline{x}},$$

then

...

x and x' ... rest energy phase between ... with mass M_ℓ

$$\phi(x,x',t) = \phi(x',t) - \phi(x,t)$$
$$= \frac{2}{\hbar}\sum_{\ell=1}^{N} M_\ell (t_{\underline{x}'_\ell} - t_{\underline{x}_\ell})$$

Remark: it is not clear what kind of a substitution should be made for t in the

$$e^{-\frac{i}{\hbar}Ht} \to ?$$

phase factor. But in the non-relativistic case

$$|H| \ll \sum_{\ell=1}^{N} M_\ell c^2,$$

therefore the leading contribution comes ... the re... energy phase factor.

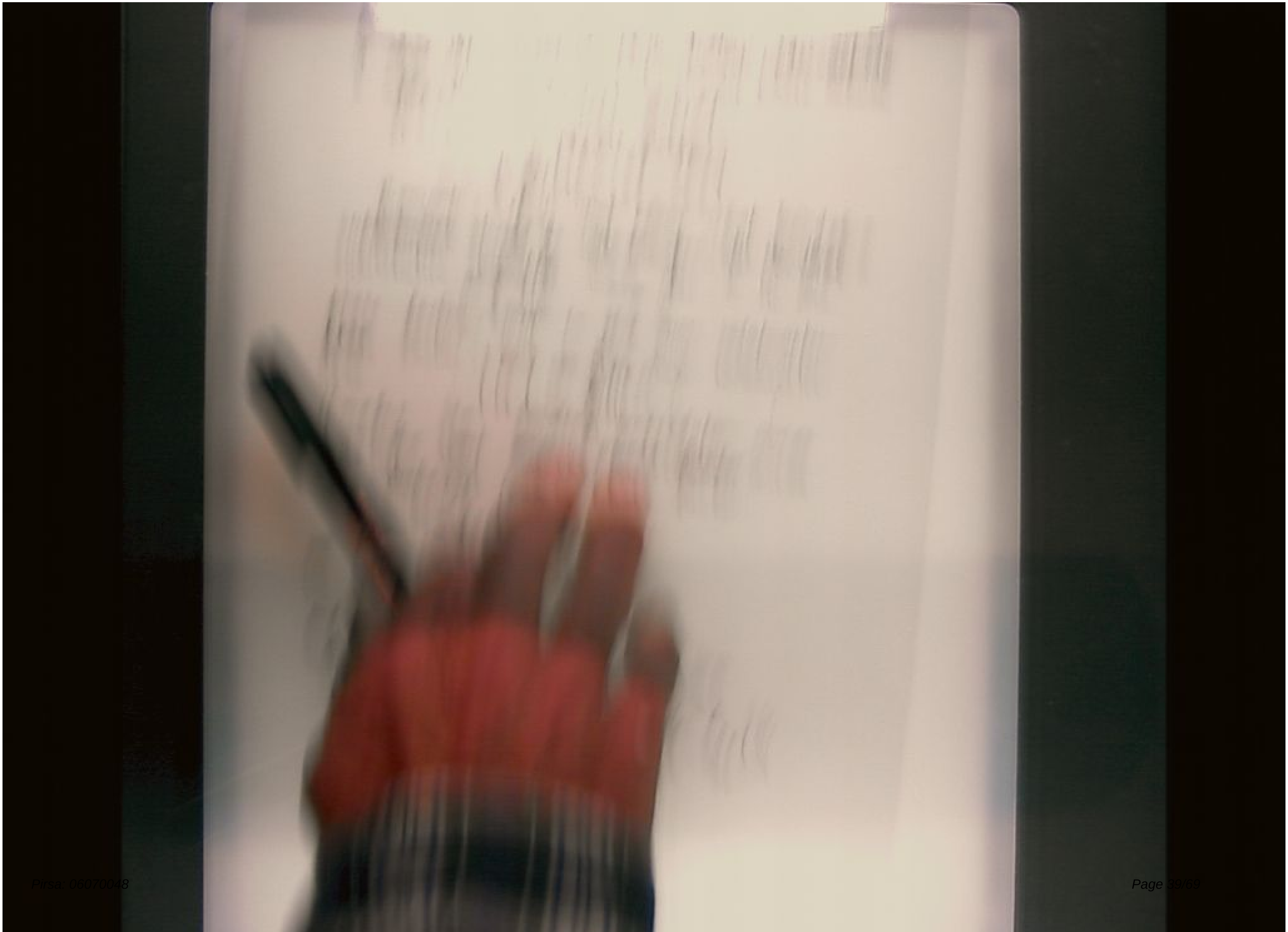
... that

$$... - t_{\underline{x}_\ell} > = 0,$$

$$... x', t) > = 0,$$

$$... (\phi(x,x',t) - 0)^2 > =$$

$$... \langle (t_{\underline{x}'_i} - t_{\underline{x}_i})(t_{\underline{x}'_\ell} - t_{\underline{x}_\ell}) \rangle.$$



phase: $\phi(t) \to \phi(x,t) = -\frac{c^2}{\hbar}\sum_{\ell=1}^{N} M_\ell t_{\underline{x}_\ell}$,

because ... coordinate of the particle with mass M_ℓ is $\underline{x}_\ell$. The relative rest energy phase between x and x' is ...

$$\phi(x,x',t) = \phi(x',t) - \phi(x,t)$$

$$= -\frac{c^2}{\hbar}\sum_{\ell=1}^{N} M_\ell (t_{\underline{x}'_\ell} - t_{\underline{x}_\ell})$$

Remark: it is not clear what kind of a substitution should be made for t in the

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phase factor. But in the non-relativistic case

$$\ldots| \ll \sum_{\ell=1}^{N} M'_\ell c^2,$$

therefore ... from ... contribution comes ... phase factor.

R...

w...

a...

$$\ldots \rangle =$$

$$\ldots \underline{x}'_\ell - t_{\underline{x}_\ell})\rangle.$$

x an

$$\phi(x, x', t) = \phi(x', t) - \phi(x, t)$$

$$= -\frac{c^2}{\hbar}\sum_{\ell=1}^{N} M_\ell \left(t_{\underline{x}'_\ell} - t_{\underline{x}_\ell}\right)$$

Remark: it is not clear what kind of a substitution should be made for t in the

$$e^{-\frac{i}{\hbar} Ht} \longrightarrow ?$$

phase factor. But in the non-relativistic case

$$|H| \ll \sum_{\ell=1}^{N} M_\ell c^2,$$

therefore the leading contribution comes from the rest energy phase factor.

Remembering that

$$\langle t_{\underline{x}'_\ell} - t_{\underline{x}_\ell} \rangle = 0,$$

we see that

$$\langle \phi(x, x', t) \rangle = 0,$$

and

$$\Delta^2_\phi (x, x', t) = \langle (\phi(x, x', t) - 0)^2 \rangle =$$

$$= \frac{c^4}{\hbar^2} \sum_{i,\ell=1}^{N} M_i M_\ell \langle (t_{\underline{x}'_i} - t_{\underline{x}_i})(t_{\underline{x}'_\ell} - t_{\underline{x}_\ell}) \rangle$$

The expression under $\langle\ \rangle$ is an algebraic sum of full squares:

$$\tfrac{1}{2}\left\langle (t_{\underline{x}_i'} - t_{\underline{x}_\ell})^2 + (t_{\underline{x}_i} - t_{\underline{x}_\ell'})^2 - (t_{\underline{x}_i} - t_{\underline{x}_\ell})^2 - (t_{\underline{x}_i'} - t_{\underline{x}_i})^2 \right\rangle.$$

Applying ** to these full squares, one finds:

$$\Delta_\phi^2(x,x') \approx \Lambda^{4/3} \frac{c^2}{\hbar^2} \sum_{i,\ell=1}^{N} M_i M_\ell \left(|\underline{x}_i' - \underline{x}_\ell|^{\frac{2}{3}} - \tfrac{1}{2}|\underline{x}_i - \underline{x}_\ell|^{\frac{2}{3}} - \tfrac{1}{2}|\underline{x}_i' - \underline{x}_\ell'|^{\frac{2}{3}} \right)$$

$\Delta\phi$ increases with the masses and with the number of the particles. These fixed, it increases with the distances $|\underline{x}_i' - \underline{x}_\ell|$, that is with the separation between x and x'. These are encouraging properties from the point of view of the expected lost of coherence between "macroscopically distinct" components of the wave fuction of a massive body.

Remark: $\Delta\phi(x,x')$ turned out to be independent of t, but it is weighted by $|\Psi(x,t)|^2 \cdot |\Psi(x',t)|^2$.

6. The C ... ce Cell and the Cell Length of a ... ngle Microparticle

For $N=1$, $i=\ell=1$. In the (... t Δ_ϕ^2 only the first term survives ... ropping the index 1 of $\underline{x}_1$, $\underline{x}'_1$ and ... one finds

$$\Delta_\phi(\underline{x}, \underline{x}') \simeq \Lambda^{2/3}\,\frac{cM}{\hbar}\,|\underline{x}'-\underline{x}| ... \frac{\Lambda^{2/3}\,a}{L},$$

where

$$L = \frac{\hbar}{cM}$$

is the Compton wav ... icle,
and

a ...

$\Delta_\phi = 0$ if ... ically
with the sep ...
is never p ...
perfect eve ...

Let us con ... er
"a". Because ...
maximal fr ...
the surface ...

$a = a$ ...

and calcula ... utron

L^{ne} ...

$\Delta_\phi^{ne}(a_{Earth})$ ...

15

Coherence Cell and the Cell Length a Single Microparticle

For $N=1$, $i=l=1$. In the ( ) of Δ_ϕ^2 only the first term survives. Dropping the index s of $\underline{x}_1$, $\underline{x}_1'$ and M_1, one finds

$$\Delta_\phi(\underline{x}, \underline{x}') \simeq \Lambda^{2/3} \frac{cM}{\hbar} |\underline{x}' - \underline{x}|^{1/3} = \frac{\Lambda^{2/3} a}{L},$$

where

$$L = \frac{\hbar}{cM}$$

is the Compton wavelength of the particle, and

$$a = |\underline{x}' - \underline{x}|.$$

$\Delta_\phi = 0$ if $a=0$, and increases monotonically with the separation a. If $\underline{x}' \neq \underline{x}$ the coherence is never perfect, but it may remain nearly perfect even for large separation.

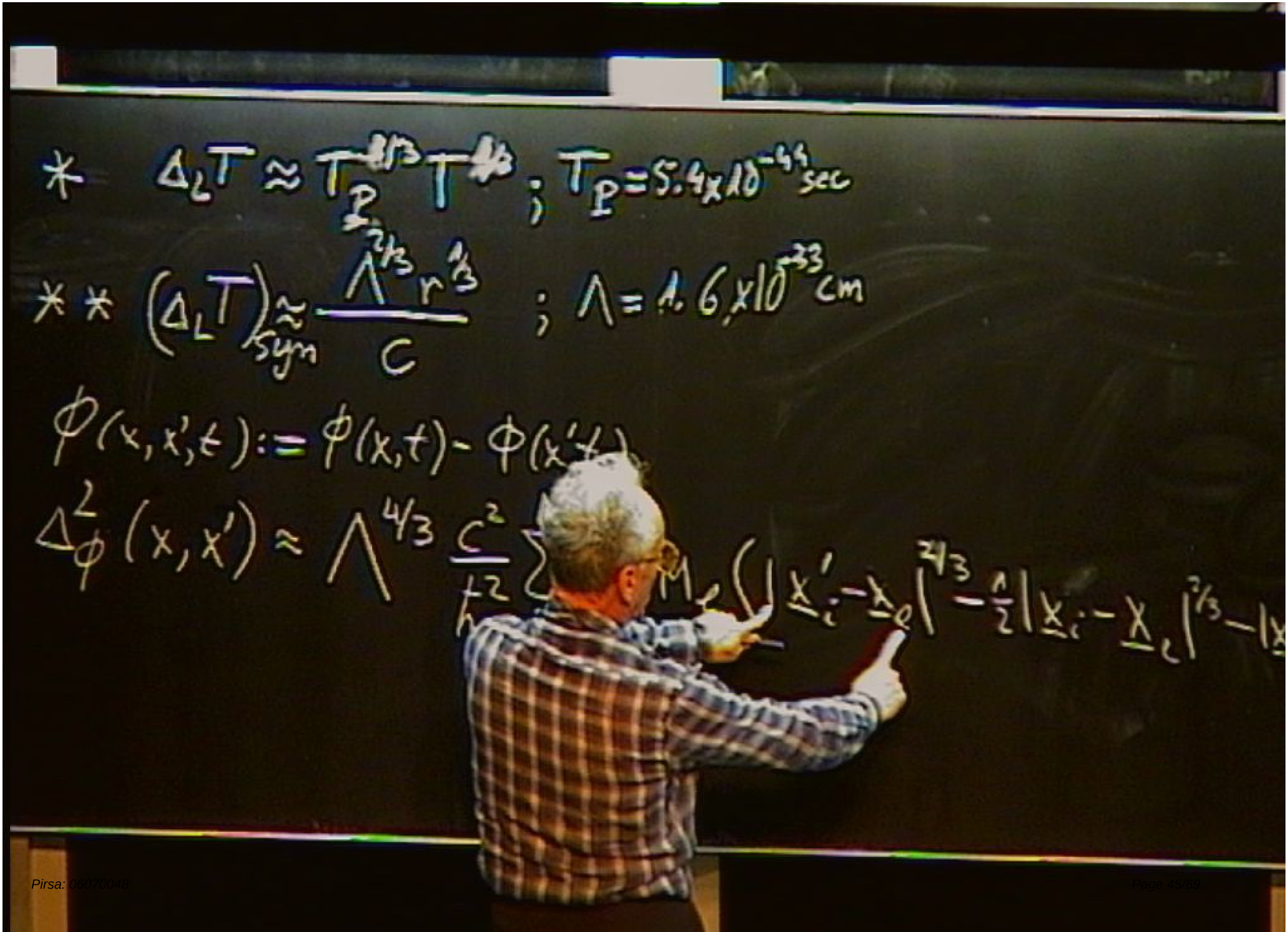
Let us consider a spherical volume of diameter "a". Because of the monotony of $\Delta_\phi(a)$, Δ_ϕ is maximal for any diametrally opposed points on the surface of the sphere. Let

$$a = a_{Earth} \simeq 10^9 \text{ cm},$$

and calculate $\Delta_\phi(a_{Earth})$ for the neutron

$$L^{ne} = 1.8 \times 10^{-14} \text{ cm},$$

$$\Delta_\phi^{ne}(a_{Earth}) \simeq \frac{(10^{-33})^{2/3}}{10^{-14}} (10^9)^{\frac{1}{3}} = 10^{-5} \ll \pi.$$


* $\Delta_L T \approx T_P^{2/3} T^{1/3}$; $T_P = 5.4\times10^{-44}$ sec
** $(\Delta_L T)_{syn} \approx \frac{\Lambda^{2/3} r^{1/3}}{c}$; $\Lambda = 1.6\times10^{-33}$ cm
$\phi(x,x',t) := \phi(x,t) - \phi(x',t)$
$\Delta_\phi^2(x,x') \approx \Lambda^{4/3} \frac{c^2}{h^2}$

$*\quad \Delta_L T \approx T_P^{2/3}\, T^{1/3}$; $T_P = 5.4\times 10^{-44}$ sec

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$$\phi(x,x',t) := \phi(x,t) - \phi(x',t)$$

$$\Delta^2_\phi(x,x') \approx \Lambda^{4/3}\frac{c^2}{\hbar^2}\sum_{i,l=1}^{N} M_i M_l \Big(|\underline{x}'_i - \underline{x}_l|^{2/3} - \tfrac{1}{2}|\underline{x}_i - \underline{x}_l|^{2/3} - |\underline{x}$$

6. Coherence Cell and the Cell Length
a Single Microparticle 15

For $N=1$, $i=l=1$. In the ( ) of Δ_ϕ^2 only the first term survives. Dropping the index 1 of $\underline{x}_1$, $\underline{x}_1'$ and M_1, one finds

$$\Delta_\phi(\underline{x},\underline{x}') \simeq \Lambda^{2/3}\frac{cM}{\hbar}|\underline{x}'-\underline{x}|^{1/3} = \frac{\Lambda^{2/3}a}{L},$$

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configura-

$$\Delta\phi(x,x') \le \pi \quad \text{for any } x, x' \in \Omega_c$$

has been called "coherence cells" (K, 1972)

For single microparticle a coherence ce... is a sphere of diameter a_c such that

$$\Delta\phi(a_c) \approx \frac{\Lambda^{2/3} a_c^{1/3}}{L} = \pi$$

Dropping the factor π^3 in a_c one finds

$$a_c \approx \left(\frac{L}{\Lambda}\right)^2 L$$

For ... neutron

$$a ... \approx \left(\frac{10^{-14}}{10^{-33}}\right)^2 10^{-14} = 10^{24} \text{ cm.}$$

Compa... with

$$a ... _{exp} \approx 10^{21} \text{ cm.}$$

Th... microparticle occupies only a tiny ... coherence cell, ψ is almost per... no self-localization is needed. ... any microsystem (composed of ...ber of microparticles free ... the " cell ... length" ... expression "coherence length"

(1972)

such that a sphere of coherence of diameter a_c

$$\Delta \phi (\ ) \approx \frac{\Lambda^{2/3} a_c^{1/3}}{L} = \pi$$

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For the neutron

$$a_c \approx \left(\frac{10^{-14}}{10^{-33}}\right)^2 10^{-14} = 10^{24} \text{ cm.}$$

Compare with

$$a_{Galaxy} \approx 10^{21} \text{ cm.}$$

The ψ of a microparticle occupies only a tiny part of its coherence cell, ψ is almost perfectly coherent, no self-localization is needed. This is so for any microsystem (composed of a moderate number of microparticles, free or bound). a_c is the "cell" "length" of [illegible] particle, the expression "coherence length" be[illegible] patented.

such that ... ence ... rameter a_c

$$\Delta\phi(a_c) \approx \frac{\Lambda^{2/3} a_c^{1/3}}{L} = \pi$$

Dropping ... factor π^3 in a_c one finds

$$a_c \simeq \left(\frac{L}{\Lambda}\right)^2 L$$

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7. The Coherence Cell and the Cell Length of Homogeneous, Macroscopic Solid Bodies

One would think that if $N \approx 10^{23}$, then nothing can be said about ψ and about $\Delta\phi$. This is not so. I have no time to go through the surprizingly simple mathematics, I just quote the result.

Let the full mass of the body be M, its diameter $2R$. The coherence cell turns out to be a sphere of diameter a_c in the center of mass coordinate subspace of the $3N$ dimensional configuration space. The contribution to $\Delta\phi$, and hence to a_c of the $3(N-1)$ relative coordinates are negligible. The formula for a_c breaks up into two parts:

[illegible] acroscopic Solid Bodies

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if $a_c \geq 2R$,

then

a_c ... $\left(\frac{\ }{\Lambda}\right)^2 L$

This fo... is the same as tha... a micropar-ticle. ... depends on M, but n... on R.

if $a_c \leq 2R$,

then

$$a_c \simeq \left(\frac{R}{\Lambda}\right)^{2/3} L$$

The formula is different from that for a microparticle, and besides M a_c depends on R too.

... consider the cases

... and $a_c \ll 2R$

... expand ... ate ... main ... e ... y

means that ψ loses its coherence already when it expands in the c.m. subspace over a domain still much smaller than R, and then a self-localization counter-balances the loss of coherence.

...nacy ...of the ...cteris- ...copic ...avior

Small indeterminacy in the position of the c.m. is characteristic of microscopic (quantum) behavior

if $a_c \geq 2R$,

then
$$a_c \simeq \left(\frac{L}{\Lambda}\right)^2 L$$

This formula is the same as that for a micropar-tide. a_c depends on M, but not on R.

if $a_c \leq 2R$,

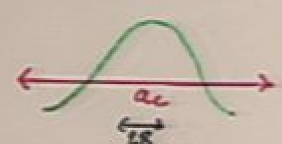
then
$$a_c \simeq \left(\frac{R}{\Lambda}\right)^{2/3} L$$

The formula is different from that for a microparticle, and besides M a_c depends on R too.

Let us consider the cases

$a_c \gg 2R$ and $a_c \ll 2R$

means that Ψ can expand in the c.m. coordinate subspace over a domain much larger than the geometrical size R of the body without losing its coherence.



Large indeterminacy in the position of the c.m. is a characteris-tic of macroscopic (quantum) behavior

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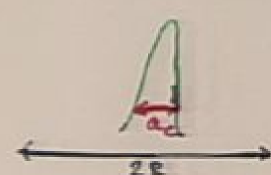

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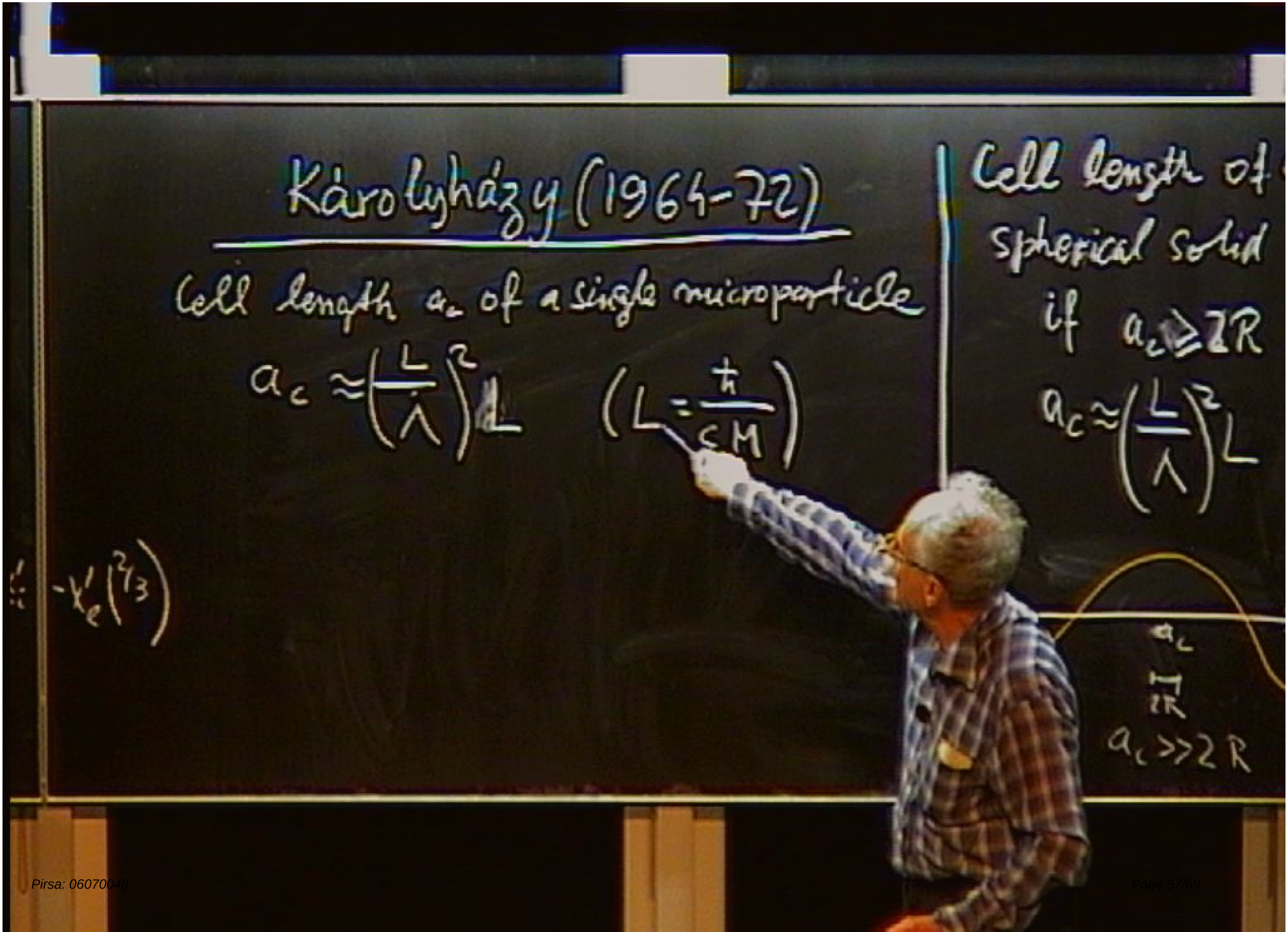
Károlyházy (1964-72)
Cell length a_c of a single microparticle
$a_c \approx \left(\frac{L}{\Lambda}\right)^2 L$
$\left(L = \frac{\hbar}{cM}\right)$
Cell length of
spherical solid
if $a_c \geq 2R$
$a_c \approx \left(\frac{L}{\Lambda}\right)^2 L$
a_c
$2R$
$a_c >> 2R$

if $a_c \geq 2R$,

then $a_c \simeq \left(\frac{L}{\Lambda}\right)^2 L$

This formula is the same as that for a micropar-ticle. a_c depends on M, bu[...]not on R.

if $a_c \leq 2R$,

then $a_c \simeq \left(\frac{R}{\Lambda}\right)^{2/3} L$

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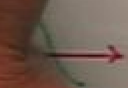
me[...] that Ψ can expand in [...] c.m. coordinate su[...]ace over a domain mu[...] larger than the ge[...]trical size R of the [...]ody without losing [...]e.



[...]nacy [...]he

means that Ψ loses its coherence already when it expands in the c.m. subspace over a domain still much smaller than R, and then a self-localization counter-balances the loss of coherence.

Small indeterminacy in the position of the c.m. is characteristic of microscopic (quantum) behavior

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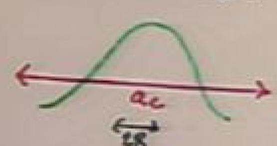
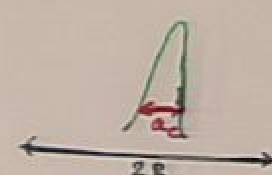
$a_c \gg 2R$ and $a_c \ll 2R$

$a_c \gg 2R$ means that Ψ can expand in the c.m. coordinate subspace over a domain much larger than the geometrical size R of the body without losing its coherence.



Large indeterminacy in the position of the c.m. is a characteris-tic of macroscopic (quantum) Behavior

$a_c \ll 2R$ means that Ψ loses its coherence already when it expands in the c.m. subspace over a domain still much smaller than R, and then a self-localization counter-balances the loss of coherence.



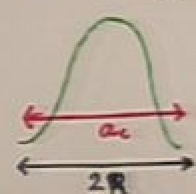
Small indeterminacy in the position of the c.m. is characteristic of microscopic (quantum) behavior

8. The Transition from Microscopic to Macroscopic Behavior

It follows from the above that the transition takes place in the region where

$$a_c \approx 2R,$$

i.e. where the indeterminacy in the position of the c.m. equals the geometrical size of the object:



Let us estimate $a_c \approx 2R$ and M in the transition region. Inserting into the formula

$$a_c \approx \left(\frac{L}{\Lambda}\right)^2 L$$

the expression

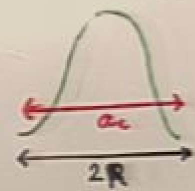
$$L = \frac{\hbar}{cM} \approx \frac{\hbar}{c\rho R^3},$$

for normal terrestrial density $\rho \approx 1\,g/cm^3$ the condition $a_c \approx 2R$ gives

$$a_c^{tr} \approx 2R \approx 10^{-5}\,cm,$$

$$M^{tr} \approx \rho R^3 \approx 10^{-14}\,gram.$$

i.e. where the indeterminacy in the position of the c.m. equals the geometrical size of the object:



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$$a_c \approx \left(\frac{L}{\Lambda}\right)^2 L$$

the expression

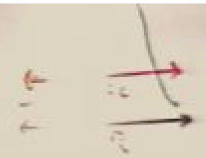
$$L = \frac{\hbar}{cM} \approx [illegible] \frac{\hbar}{[illegible] \rho R^3},$$

for normal terr[illegible]al density $\rho \simeq 1 g/cm^3$ the condition a_c [illegible] R gives

$$a_c^{tr} \simeq [illegible]$$

M^{tr} [illegible] m.

This is [illegible] l colloidal grains and [illegible]



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$$a_c^{tr} \approx 2R \approx 10^{-5}\, cm,$$

$$M^{tr} \approx [illegible]^3 \approx 10^{-14}\, gram.$$

[illegible]is is [illegible]ss region of colloidal grains [illegible]f d[illegible]ticles.

The[illegible]
responsible for the loss of the coherence, because if it were, then the transition from quantum classical behavior should take place the region of the Planck mass

$$M_P = \frac{\hbar}{c\Lambda} = 2.2\times 10^{-5} \text{ gram.}$$

However, a body of such a large mass is known to behave classically, it does not belong to the transition region.

As we have seen, only the amount of the indeterminacy of the space time structure is fixed by M_P (or, wh[illegible] is the same, by $T_P = \hbar/M_P c^2$). The [illegible]gree of the loss of coherence is given [illegible] $\Delta\phi$, which depends not only on M_P, but also on the physical composition of the system considered, in particular on the masses of its [illegible]tuents. This leads to

$$M^{tr} \simeq 10^{-15} \;[illegible]\; M_P,$$

a plausible va[illegible]

For a tiny g[illegible] gram $R \simeq 10^{-6}$ cm, and

$a_c \simeq$ [illegible] (grain)

For a [illegible]

a[illegible]

take
mass

$$M_P = \frac{\hbar}{\cdot\Lambda} = 2.2\times 10^{-5}\ \text{gram}.$$

However, a such a large mass is known to behave classically, it does not belong to the transition region.

As we have seen, only the amount of the indeterminacy of the space-time structure is fixed by M_P (or, what is the same, by $T_P = \hbar/M_P c^2$). The degree of the loss of coherence is given by $\Delta\phi$, which depends not only on M_P, but also on the physical composition of the system considered, in particular on the masses of its constituents. This leads to

$$M^{tr} \simeq 10^{-15}\ \text{gram} \ll M_P,$$

a plausible value.

For a tiny grain of $M \simeq 10^{-18}$ gram $R \simeq 10^{-6}$ cm,
and

$$a_c^{grain} \simeq 10^5\ \text{km} \gg \ldots$$

For a ball of $M \simeq \ldots$ gram $R \simeq 1$ cm, and

$$a_c^{ball} \simeq 10^{-16} \ldots \ll 2R.$$

take
mass

$$M_P = \frac{\hbar}{\cdot\Lambda} = 2.2 \times 10^{-5} \text{ gram.}$$

However, a such a large mass is known to behave classically, it does not belong to the transition region.

As we have seen, only the amount of the indeterminacy of the space-time structure is fixed by M_P (or, what is the same, by $T_P = \hbar/M_P c^2$). The degree of the loss of coherence is given by $\Delta\phi$, which depends not only on M_P, but also on the physical composition of the system considered, in particular on the masses of its constituents. This leads to

$$M^{tr} \simeq 10^{-15} \text{ gram} \ll M_P,$$

a plausible value.

For a tiny grain of $M \simeq 10^{-18}$ gram $R \simeq 10^{-6}$ cm, and

$$a_c^{grain} \simeq 10^5 \text{ km} \gg R.$$

For ball of $M \simeq 1$ gram $R \simeq 1$cm, and

$$a_c^{ball} \simeq 10^{-16} \text{ cm} \ll 2R.$$

take
mass

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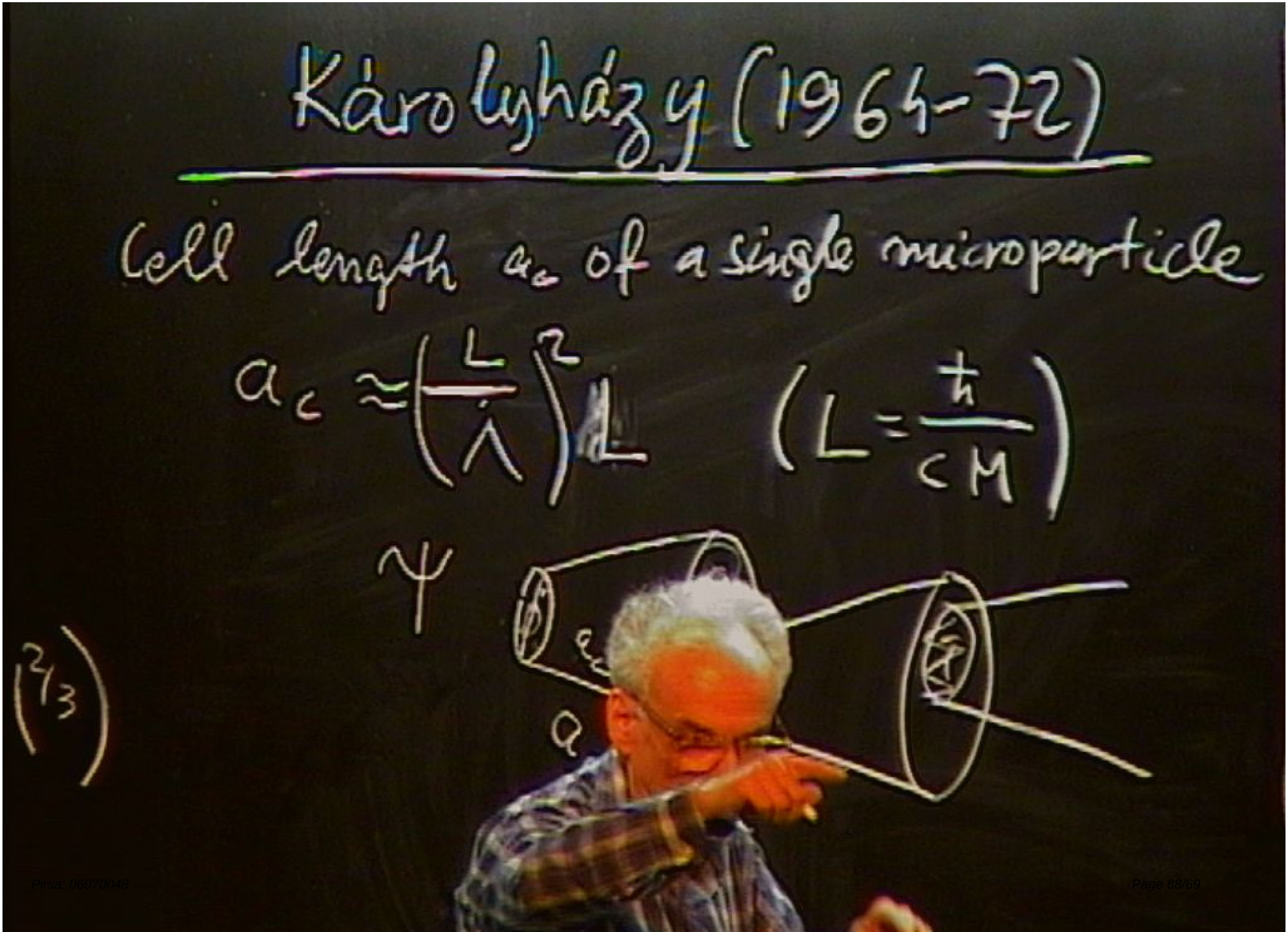
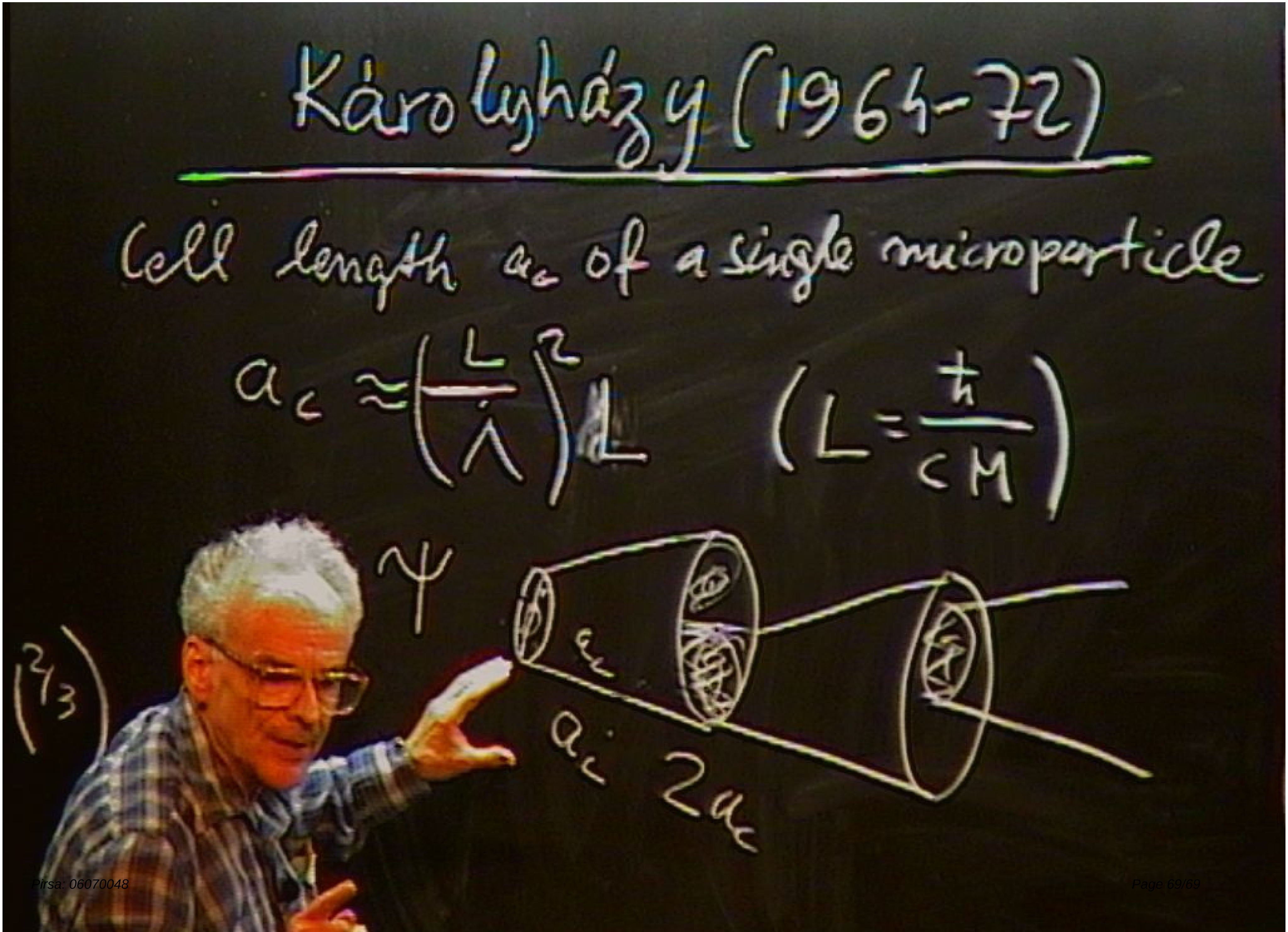
15. Concluding Remark

According to the orthodox view, in order to extract observable results from QM one needs at least one agent which does not obey the laws of QM, but behaves "classically".

However, if one abandons the concept of the sharp space-time structure, and with it the unlimited validity of the superposition principle, the division of the world into objects with purely quantum mechanical or purely classical behavior is not needed. The time evolution of any object obeys a unified dynamics, combining the deterministic Schrödinger ~~time~~ evolution with the stochastic self-localizations. Because of "practical" reason microparticles do not undergo self-localization, but in principle they could. For solid macroobjects the self-localizations occur frequently, and they would keep the localization of the c.m. very tight even if the body would be completely isolated, and if nobody would observe it.


Károlyházy (1964-72)
Cell length a_c of a single microparticle
$a_c \approx \left(\frac{L}{\lambda}\right)^2 L \quad \left(L = \frac{\hbar}{cM}\right)$
Ψ
a_c
a
$\binom{2}{3}$


Károlyházy (1964-72)
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a_c
$2a_c$
$(2/3)$