Title: Conceptual problems in phenomenological interpretation in searches for variation of constants and violation of various invariances

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Abstract: At present a number of current or proposed experiments are directed towards a search for a `new physics\' by detecting variations of fundamental physical constants or violations of certain basic symmetries. Various problems related to the phenomenology of such experiments will be considered.

Conceptual problems in phenomenology for searches for `new physics'

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MPQ

Why new physics via precision atomic study?

We observe at present:

A **fantastic** progress in precision atomic studies

- quantum optics with manipulations on single atoms and precision measurements is the most dynamic part of modern physics
- 3 Nobel prices in 9 years for recent results!

A **terrible** shortage of data and very slow progress on

- a possible extention of the Standard model of electroweak and strong interactions
  - (even on details of the Standard model – still no Higgs particle has been seen up-do-date);
- quantum gravity.

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What is good for atomic physics should be useful for the rest of physics.

Why not to go for `new physics´?

Outline

- Variations of constants
- Physics at the Planck scale
- CPT
- Violation of symmetries

- General discussion
- Examples
  - Examples
    - Examples
      - Examples
        - Examples
          - ...

Testing `old physics´ and looking for `new physics´

Two kinds of experiments

Some pretend to be model-independent.

The others are model-dependent.

Both are not free
off conceptual problems,
`hidden´ arbitrary suggections
and missintepretations.

Examples: Variations and LTI

Variation of a constant A means that

$$A(t_1) \neq A(t_2)$$.

LTI (Local Time Invariance), a part of `big´ relativistic invariances, requires in particular that a result of a measurement of a fundamental scalar value for t_1 and t_2 should be the same.

Examples: Variations and LTI

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LTI (Local Time Invariance), a part of `big´ relativistic invariances, requires

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Often it is belived that
LTI is equvivalent to **non-variation**
of the fundamental constants.

However, that is not.

Examples: Variations and LTI

LTI suggests `fundamental experiments´:

- free particles,
- free space,
- no environment,
- etc.

Example of the environment:

- local gravity is changing in time because of the Sun and the Moon at a 1-ppm level;
- *g* can be measured at 10-ppb level.

Examples: Variations and LTI

LTI suggests `fundamental experiments´:

- free particles,
- free space
- no enviror
- etc.

Example of the environment:

- local gravity is changing in time

In modern precision study the `environment´ may be something far outside of the lab.

Matter, **dark matter**, **bath of Cosmic Microwave Background (γ, ν, g).**

Examples: Variations and LTI

LTI suggest

Example of the

...nent:

...vity is

...g in time

The inflation model:
once and long long time ago
in a very remote past
(even before MPQ was established
and before hydrogen atoms were formed)
real changes in values of m_e, α, m_p took place.

- etc.

... study

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...of the lab.

Matter, **dark matter**,
bath of Cosmic Microwave Background (γ, ν, g).

Examples: Variations and LTI

LTI suggest

Example of the

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Why?

Because of cooling of the Universe.

The very Universe acted
as a piece of the environment
and caused a phase transition
changing m_e, α, m_p etc:

no violation of LPT,
but still the variations took place.

Examples: EDM of an electron

Common knowledge:

- Modern theory allows no EDM until some violations of basic symmetries are involved.
- A standard electron has the EDM because of CP violation in Standard model (SM) but it is below any detectable level.
- The motivation for a seacrh of a bigger value of the EDM is due to extentions of the SM.
- Their allowed range is for about 5 orders of magnitude.
- The results relate to half of the range (in the logarithmic scale) and they are negative.

The interpretation is model-independent.

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Correct!

Incorrect!

Model-dependent!

The interpretation is model-independent.

Examples: EDM of an electron

What else can induce the EDM?

- Modern theory allows no EDM until some violations of basic symmetries are involved.
- If some relativistic invariances are violated (isotropy, the Lorentz invariance) that could produce the EDM.

A violation of the Lorentz invariance.

- The preferred frame.
  - `Local´ - Dark Matter
  - `Global´ - CMB
- The EDM can be directed not along the spin **s**, but along the velocity **v** in respect to the preferred frame or along [**v**×**s**].

Examples: EDM of an electron

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- Dark Matter

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along [$\mathbf{v}\times\mathbf{s}$].

That is indeed
a very different situation.

Different experiments are needed.

But still:

that is the EDM.

`Variation of the constants´

- The very wording is inconsistent: `constants´ cannot very.
- That is not a problem of semantics.
- The very conception of `constants´ assumes:
  - there are certain basic equations
  - and there are certain parameters there.
- `Variation of the constants´ suggests that we can
  - keep the equations,
  - but vary their constants.
- **That** is inconsistent.
- If we want `to change´ the constants, we have to re-consider the equations.

Two examples:

The Maxwell equations of propagation of a photon at media (which obviously violate LPT, LTI, isotropy and relativity)

- not just $c(t,x)$,
- but:
  - $\varepsilon(t,x)$
  - $\mu(t,x)$
  - and their time and space gradients are present in basic equations!

A model:

- a space-time with $\hbar(t)$, but not with $\hbar(x)$ – that an isotropic situation!
- the electron´s spin angular moment, L, is conserved, but

$$J_z = \pm \tfrac{1}{2}\hbar(t)$$

which is inconsistent.

The Feynman´s continual integral and the interference

The soul of quantum theory is interference and a way to include it as a base principle as a continual integral.

- Quantum mechanics is based on the path integral (over possble trajectories).
- Quantum field theory is based an integral over all evolving field configurations.

The action is the phase.

The least action is an enhanced trajectory leading to classical mechanics.

Modification of `old physics´

- We should take the most fundamental level (quantum field theory).
- We should write the proper confinual integral.
- We should introduce various dimensionless factors $\zeta(x,t)$.
- A chage c -> c $\zeta(x,t)$ is a kind of description of c(t).
- Example:
  in classical electrodymanic Lagrangian a substitute

  $$\mathbf{E}^2 + \mathbf{B}^2 \to \varepsilon\mathbf{E}^2 + \mathbf{B}^2/\mu$$

  leads to the Maxwell equations in media, properly introducing gradients of $\varepsilon(x,t)$ and $\mu(x,t)$.

Modification of `old physics´

- We should take the most fundamental level (quantum field theory).
- We should write the

E and **B** are components of $F_{\mu\nu}$, the same quantities used for the vacuum case.

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Modification of `old physics´

- We should take the most fundamental level
- Example: in classical

In fact even in Lagrangian some gradients can appear.

If we start from dX/d(ct) we can substitude it for

(1/c)(dX/dt) or (d/dt)(X/c) or dX/d(ct) .

Going from Lagrangian to equations we produce more gradients.

c(t).

Gradient terms (GT)

- GT allow to look for variations of dimensional quantities:
  - detecting gradient rates
  - directly comparing quantities (not the results!) for different cases (like the MM experiments)
- Gradients can be introduced only on base a model and the results are most likely model-dependent.

Gradients and different kinds of searches for variations

There are three kinds of searches for variations of fundamental constants, which differently deal with GT

- fast measurements – long separation
- monitoring
- differential measurements

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- Fast measurement – gradient effects ~ $dX/dt \times \tau$.
- Long separation – difference

$X(t+T) - X(t) \sim dX/dt \times T$.

- $T \gg \tau$. The gradient effects can be neglected.
- These measurements deal with dimensionless results.

Gradients and different kinds of searches for variations

There are three kinds of searches for variations of fundamental constants, which

measurements

- Fast measurement – gradient effects ~ dX/dt × τ .
- Long separation –

dt × T.

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In atomic spectroscopy:

the time of the measurement is a combinaiton of the interaction time (photon + atom) and the coherence time.

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- fast measurements – long separation
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That can be

- a continuos measurement
- long measurements – long separation
- phase-coherent separated measurements.

- For any of them T ~ τ. The gradient effects cannot be neglected.
- Any interpretation need a `complete´ theory.

Gradients and different kinds of searches for variations

What is `the phase coherent separated measurements´?

That is a kind of a classical Ramsey-scheme experiment.

Dealing with an atom we do not `know´ the position of an electron and we study a kind of average radius.

Dealing with a planet we see the phase of its rotation.
Even doing `fast measurements´ with `long separation´, but `remembering´ the phase, we should still deal with GT.

That can be

- a continuos measurement
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- long measurements – long separation
- phase-coherent

Likely all tests of General Relativity and searches for variations of G are a kind of monitoring.

No particular constraint on dG/dt obtained without any assumption of GT cannot be correct!

Gradients and different kinds of searches for variations

What is `the phase coherent

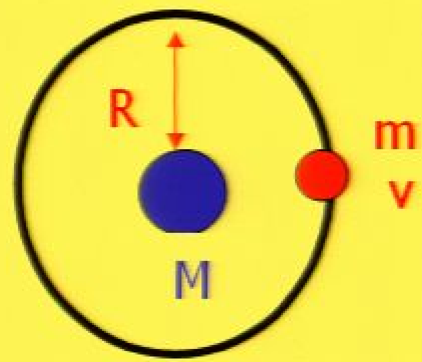
Another example: measuring R in two body system.

For simplicity: $M \gg m$ and a circular orbit

Everything is stable:
Keppler´s law: $v^2 R = GM$,
a conservation of $v = 2\pi R/T$
and no dependence on m.

If G, M and m are changing there are two effects:
changing GM shifts R directly,
changing m but keeping $p=mv$ shifts v and thus R.

The results can be found from conservations laws:
$R = GM \times m^2/p^2$.



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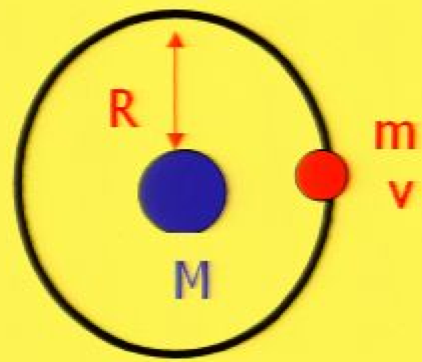

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From equaitons of motion:

changing GM – no gradients,
changing m produces term
$m\,a = \ldots - v\,dm/dt$.

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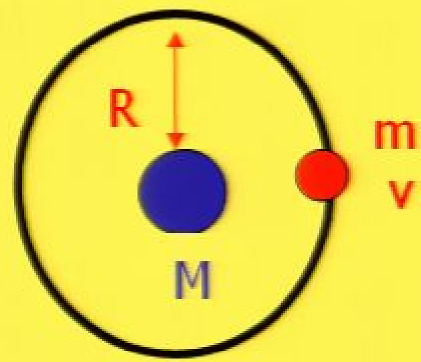

And to be precise we got a result for a time variation of

$GM \times m^2 m_e$,

which is in a quite realistic scenario

$\sim m_p^3 m_e / M_{Pl}^2$.

That is dimensional which can be because of a gradient effect is involved.

From equaitons of motion:

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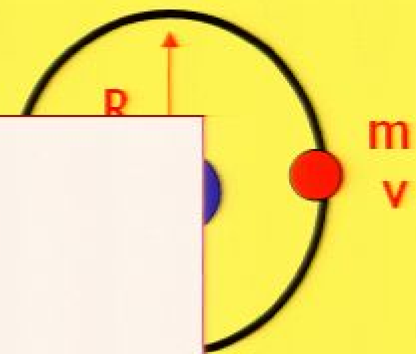

Mass cannot change in conventional physics.

The choices:

1. Use a `completely new physics'.

2. Use a modification of old physics:
e.g. *m* is varying because it picks up certain amount of dark matter or dust or because of evaporation and radiation. – That reads: we introduce a mechanism which may imply transfer of other values (E, p, L etc).

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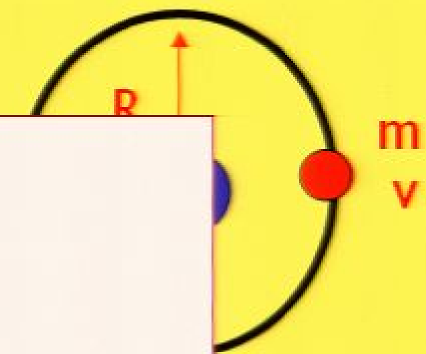

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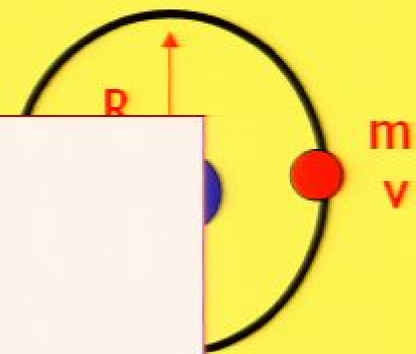

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- fast measurements – long separation
- monitoring
- differential measurements

- Experiment directly sensitive to a gradient of a constant
  - e.g. for a transition which is proportional to the gradient
  - Those experiments are obviously model-dependent.
- MM-like experiments

Gradients and different kinds of searches for variations

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- MM-like experiments

MM-experiments are also model dependent.

The renormalization and the Planck-scale physics

- We believe that the most fundamental physical quantities are defined at the Planck scale.
- We observe various effects at energy scale much below the Planck scale.
- To build a really fundamental theory we should express observables in terms of the Planck-scale-determined values,
- which we cannot do.

The renormalization and the Planck-scale physics

- We believe that the most fundamental physical quantities are de… sc…
- W… ef… m… sc…

- To build a really fundamental theory we should express … of

In a sense we have not a fundamental theory,
but a `**fundamental constraint**´.

It is not a theory, but a **constraint**, in a sense that
we **cannot predict** *ab initio* the experimental results,
but only **relations** between them.

It is a **fundamental** constraint in a sense, that
we need to perform **very few** measurements
to predict **a lot**.

The renormalization and the Planck-scale physics

The main problem is the Planck-scale physics.

We cannot derive any properties for `our´ energies from there because of lack of knowledge about their physics.

Instead, we have developed the renormalization procedure which allows to avoid any involvement of that physics into low-energy calculations.

Such approach is successful and one can expect that we cannot see any effects from the Planck-scale physics at all.

That is not correct.

We are still able to see dynamics at the Planck scale if any.

Simple example: a compactification with R(t).

The renormalization and the Planck-scale physics

The example:

a multidimensional world. All space dimensions, but 3, are compact with compactification radius R, which is ~ Planck length, but R = R(t).

In such a case, R(t) could enter the renormalimalized results, e.g.,

$$\alpha = \alpha_0 \left(1 + k\, \alpha_0 \ln(m_e R)\right) .$$

As long is α_0 is a constant, we can see no effects related to α_0, because all results, such a the Lamb shift, are expressed in terms of α.

Still: we should see variation of α, caused by the Planck scale via R(t).

involvement of that physics into low-energy calculations.

Simple example: a compactification with R(t).

The renormalization and the Planck-scale physics

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A classical/quantum analogy:

Usually, quantum effects are small and
dealing with classical macroscopic bodies
we can hardly see effects
from the quantum scale.

However, we can see non-consevration effects.

In classical physics the mass is conserved.
In quantum it does not.

Measuring classical massed we can see that.

Another example: no problem to see radioactivity.

The MM experiment and the Planck scale physics

- The experiment

  The classical MM experiment suggested that the path of a light, determined by a ruler of a solid-state bulk matter remains the same, while the velocity of the ligth could change if we change the direction of the propagation.

- A suggesiton:

  In the leading approximation the length of a substance ruler is determined by the Coulomb force in the atoms.

- The question:

  Is the Coulomb force relativistic or not?

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- The question:

  Is the Coulomb force relativistic or not?

The answer: **It depends!**

The MM experiment etc: two scenarios

The basic question is what is the fundamental quantity?

- The charge.
- Its value is a result of, e.g., spontanous breakdown, not related to relativity.
- The Coulomb law is

$$\sim Z_1 Z_2 e^2/r$$

- We can violate the relativity not affecting the charge and the Coulomb law.

The path does not change.

- The fine structure constant α is calculable (at the Planck scale).
- The charge is calculable via α, $\hbar$, c. The Coulomb law is

$$\sim Z_1 Z_2 \alpha \hbar c/r$$

- If we violate the relativity, the Coulomb law is sensitive to that.

The path changes.

The MM experiment etc: two scenarios

The basic question is what is the fundamental quantity?

- The charge.
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The path changes.

A suggestion related to the Planck scale is crucial
for the interpretation
of the classical MM experiment.

How to violate a symmetry?

- A direct violation:
  the mass as a violation of the left-right symmetry
- Anomaly
  π^0 decay:
  - a singularity
  - the regularization is possible only for a part of symmetries
- Spontanous breakdown
  the Standard model;
  maghetic properties:
  - the potential is symmetric
  - the symmetric states are not stable
  - the least energy states are not symmetric

How to violate a symmetry?

- A direct violation:
  the mass as a violation

Analogy: when we measure L_x and L_y,
that is well defined in classical mechanics,
but needs additional `**regularizations**´
in quantum mechanics, by e.g., saying
that L_x is measured at $t - \varepsilon$ and
L_y is at $t + \varepsilon$ with $\varepsilon \to 0$

The result depends on sign of ε.

After `regularizing´ the measurements,
both L_x and L_y are still conserved,
but the conservations cannot be seen at one time.

- Spontanous breakdown
  - ...e Standard model;
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- Anomaly
  π^0 decay:
  - a singularity [...]
  - the regulariz[...] possible only [...] part of symm[...]

Example: left-handed and right-handed organic molecules.

Electrodynamics is isotropic, but there is no stable state symmetric in respect to reflection x -> -x.

Usual symmetric combination of LH and RH molecules does not work because the tunel transition time is too large.

The LH asymetric molecule is destroyed much much faster that the ocsillation period.

How to violate a symmetry?

Observational problems:

- we cannot look for a symmetry, but only for its consequenses;
- the symmetry may be conserved, but its naive consequences would be incorrect.

- Non-commutativity of the coordinates in quantum gravity.

An analogy:

- Classical mechanics:

  For isotropy we can measure L_x, L_y, L_z and repeat the measurements.

  The results stand the same.

- Quantum mechanics: the results are not the same even for an isotropic problem.

How to violate a symmetry?

The most natural language for a direct violation is external field:

- classical (matter, dark matter etc);
- quantum (condensate).

Such a field may be very similar to conventional electromagnetic or gravitational field, but is is `selective´.

How to violate a symmetry?

The most natural

Such a field may be

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eld,

tive´.

What does it mean `selective´?

The electric field is universal in a sense, that its interaction is of the same form for any elementary particle.

The difference is only a charge of a particle, which is 0 or ±1 for free particles.

CPT violation and a `selective´ field: an example

What experimentalists want for CPT:

- different charges – not good because of gauge invariance and charge conservation;
- masses:

  $m_\pm = m_0 \pm \delta m$

We can rewrite that as

$m_\pm = m_0 + qeU$

where $q = \pm 1$

and $U = \delta m/e$.

U is an effective potential.

As long as we deal only with electrons we cannot see any effects due to U.

CPT violation and a `selective´ field: an example

What experimentalists

If we deal with few kinds of particles (e, μ,...) and $U_e \neq U_\mu$, i.e., if the field is selective, we can observe effects proportional to $U_e - U_\mu$, e.g. the muon decay.

The result is **not** CPT asymmetry of the mass.

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where $q = \pm 1$

and $U = \delta m/e$.

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CPT violation and a `selective´ field

- The selective potential U is similar to Kostelecky´s a term.
- Some other terms are similar to the magnetic field.

The true magnetic field universaly interacts with
spin and orbital motion
(of the same particle)
and with different particles.

- The parametrization is related to the vacuum.
- Often in experiments we should deal with residual electromagnetic fields.
- We shield from them.
- The shielding may be based on re-distribution of the electron
  - charges
  - currents
  - spins

CPT violation and a `selective´ field: example

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$$e\,\mathbf{j}_i\,\mathbf{A}_i + \mu_i\,\mathbf{s}_i\,\mathbf{B}_i$$

For true residual magnetic field:

$$\mathbf{B} = \mathbf{B}_i = \text{rot}\,\mathbf{A}_i$$

For violated symmetry they are small and independent.

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For true residual magnetic field
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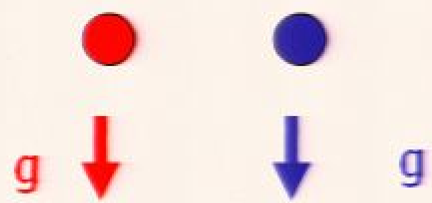
For violated symmetry they are sr
and independent.

When shielding residual magnetic field by rearranging´electron spins we change the effective hamiltonian to

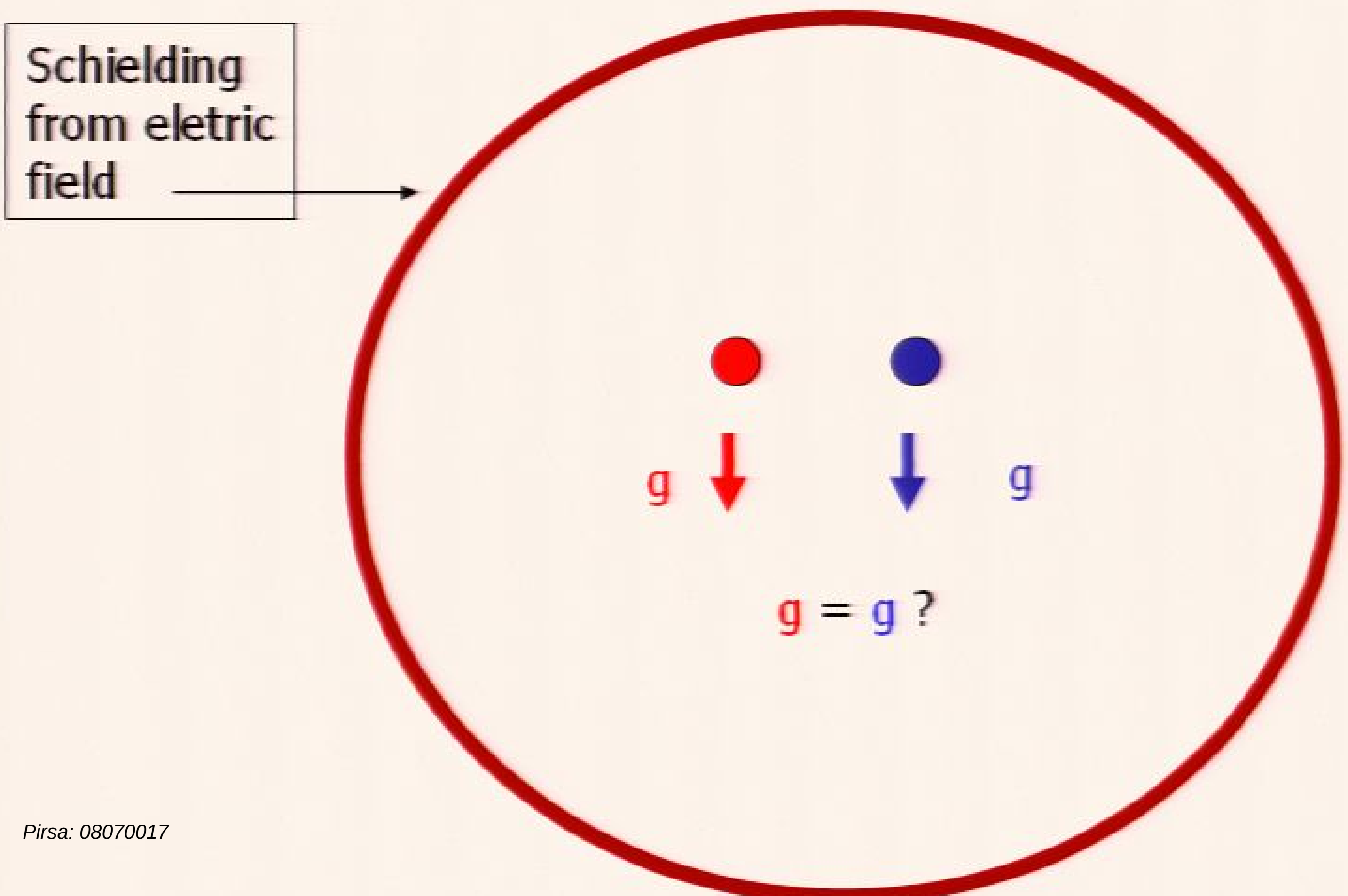
$$e\, \mathbf{j}_i\, (\mathbf{A}_i - [\mathbf{r} \times \mathbf{B}_e]) + \mu_i\, \mathbf{s}_i\, (\mathbf{B}_i - \mathbf{B}_e)$$

CPT: gravity of electron and positron



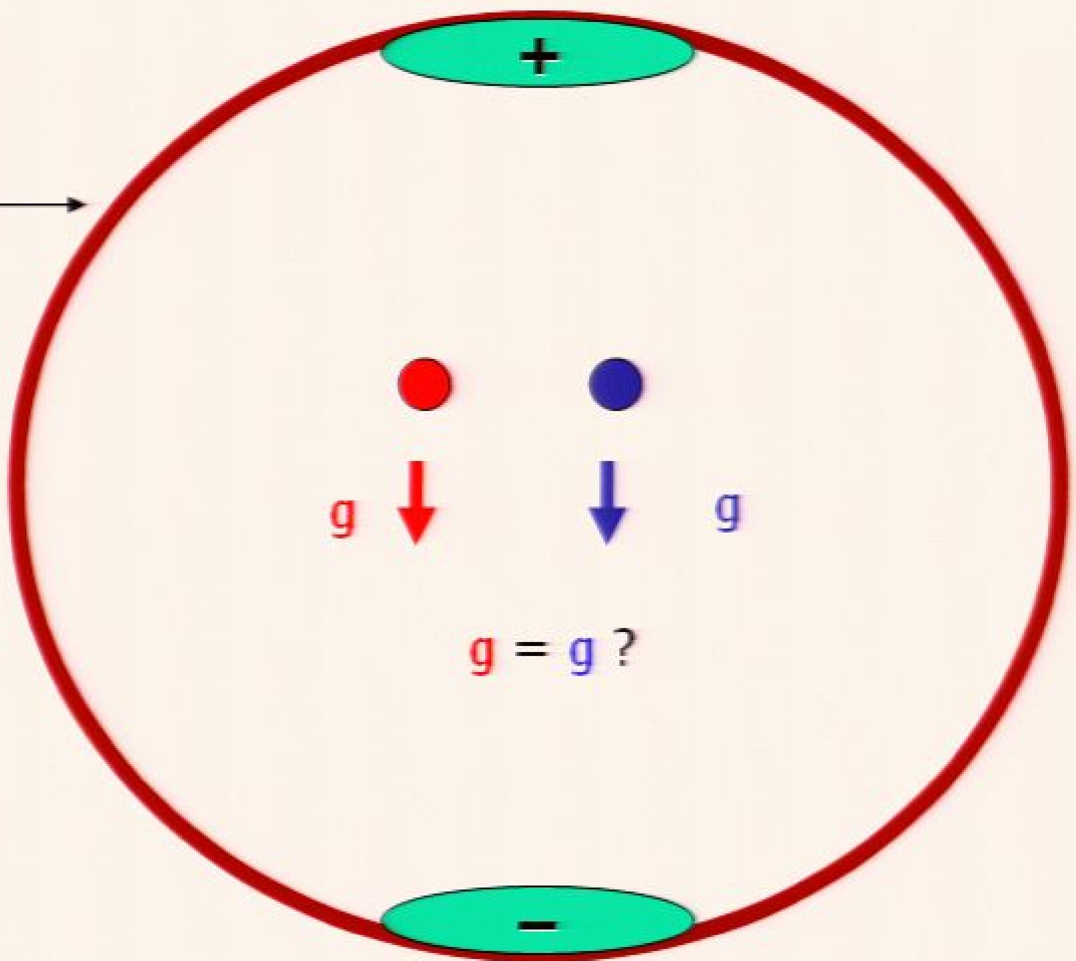
g = g ?

CPT: gravity of electron and positron

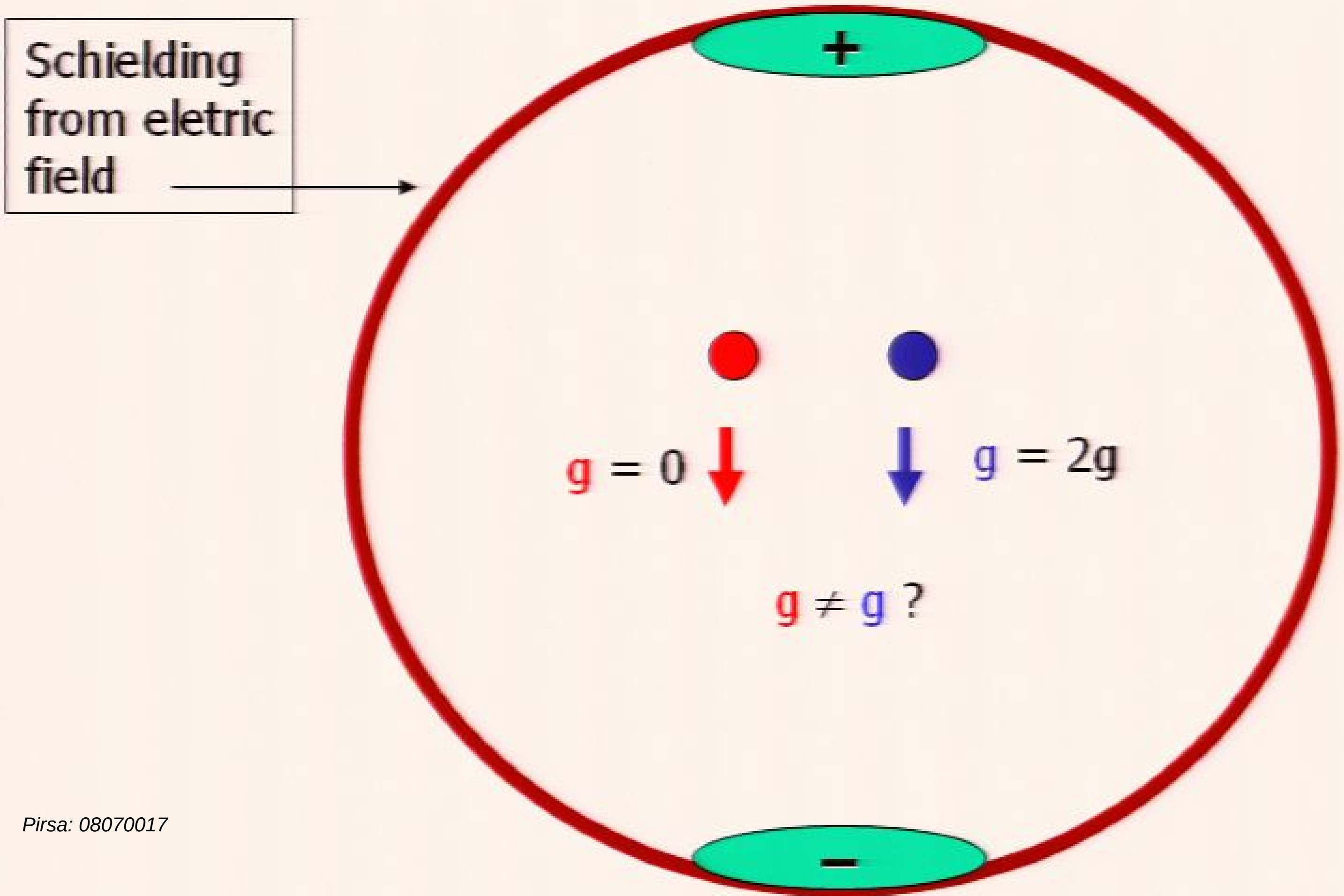


CPT: gravity of electron and positron

Schielding from eletric field

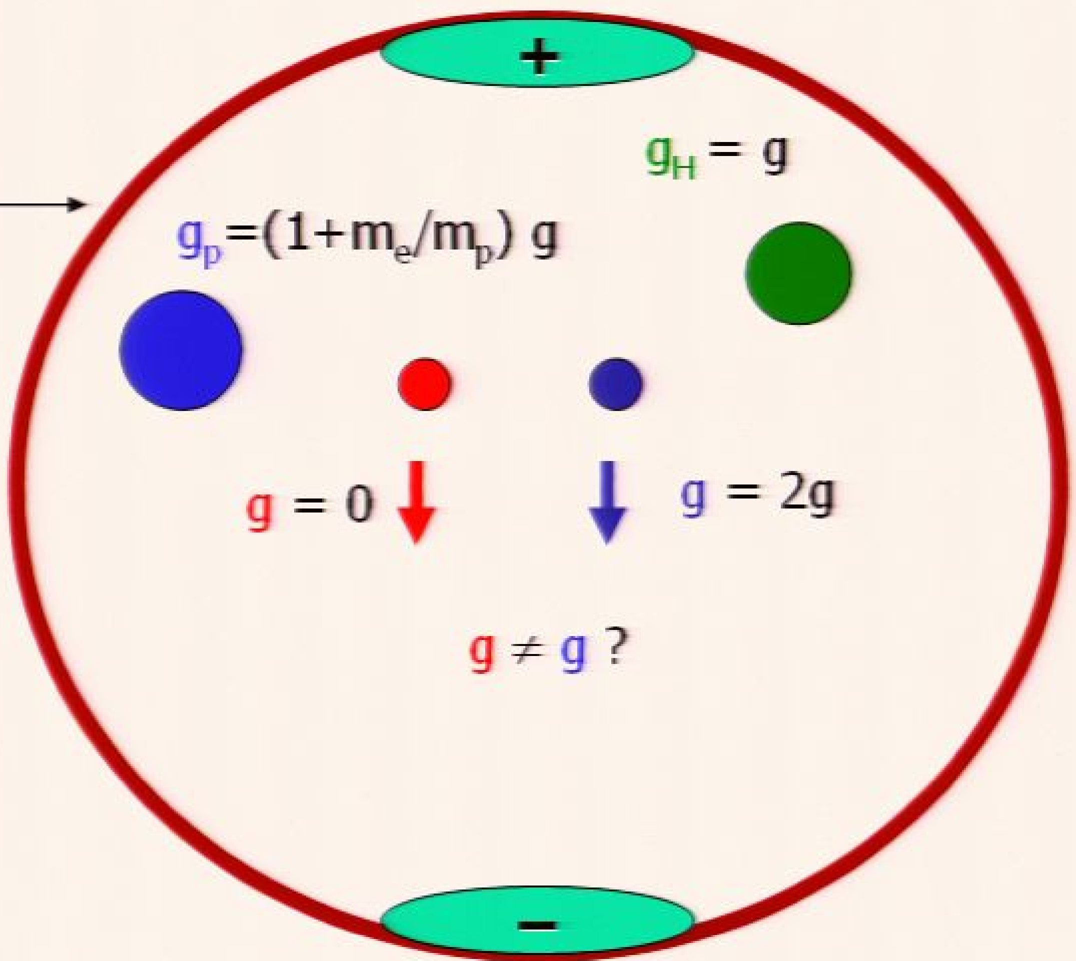


CPT: gravity of electron and positron



Gravity of electron, positron, proton, and hydrogen

Schielding from eletric field



Why these fancy `violating terms´ looks as the fields?

When we want to build a theory we are very limited in what we can write. The result should be relativistic invariant, local etc.

Violating fields and true fields (EM or G) satisfy similar conditions.

However, when we have a true fundamental theory (EM or G) we have certain constraints on relation between different terms (spin/orbit; Newton/PostNewton) and a kind of universality (conservation of charge, mass etc).

Without all those constaints the interaction would be `selective´!

Microscopic and macroscopic description

- One more issue about effective fields and equations is due to their scale.
- An example: a kind of classical-field effect can be caused by dark matter.

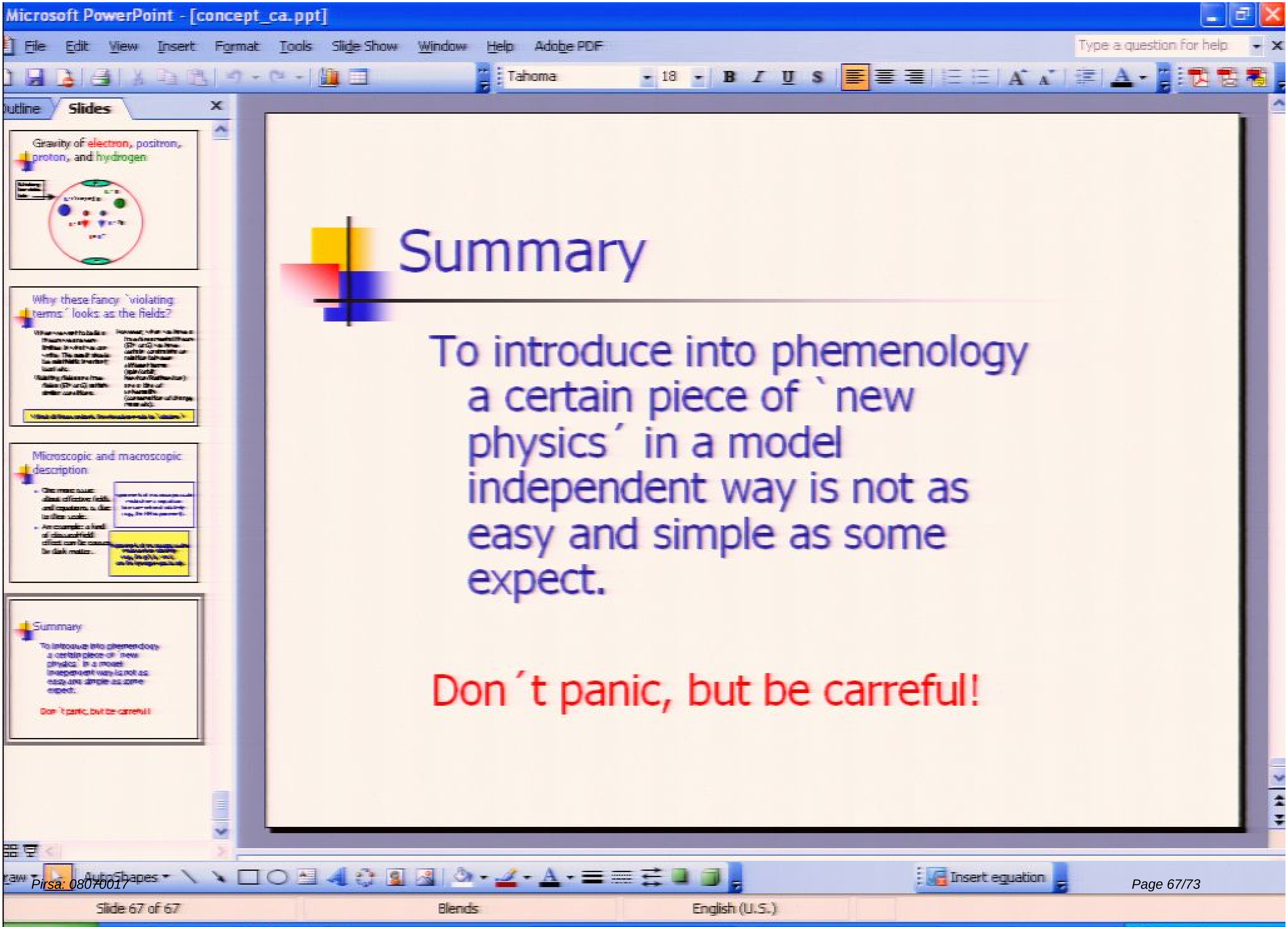
Experiments of macroscopic scale would show a departure from conventional relativity (e.g., the MM experiment).

Experiments of microscopic scale would confirm relativity (e.g., the g-2, $E_0=mc^2$, and the hydrogen spectrum).

Summary

To introduce into phemenology a certain piece of `new physics´ in a model independent way is not as easy and simple as some expect.

Don´t panic, but be carreful!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Gravity of electron, positron, proton, and hydrogen
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Microscopic and macroscopic description
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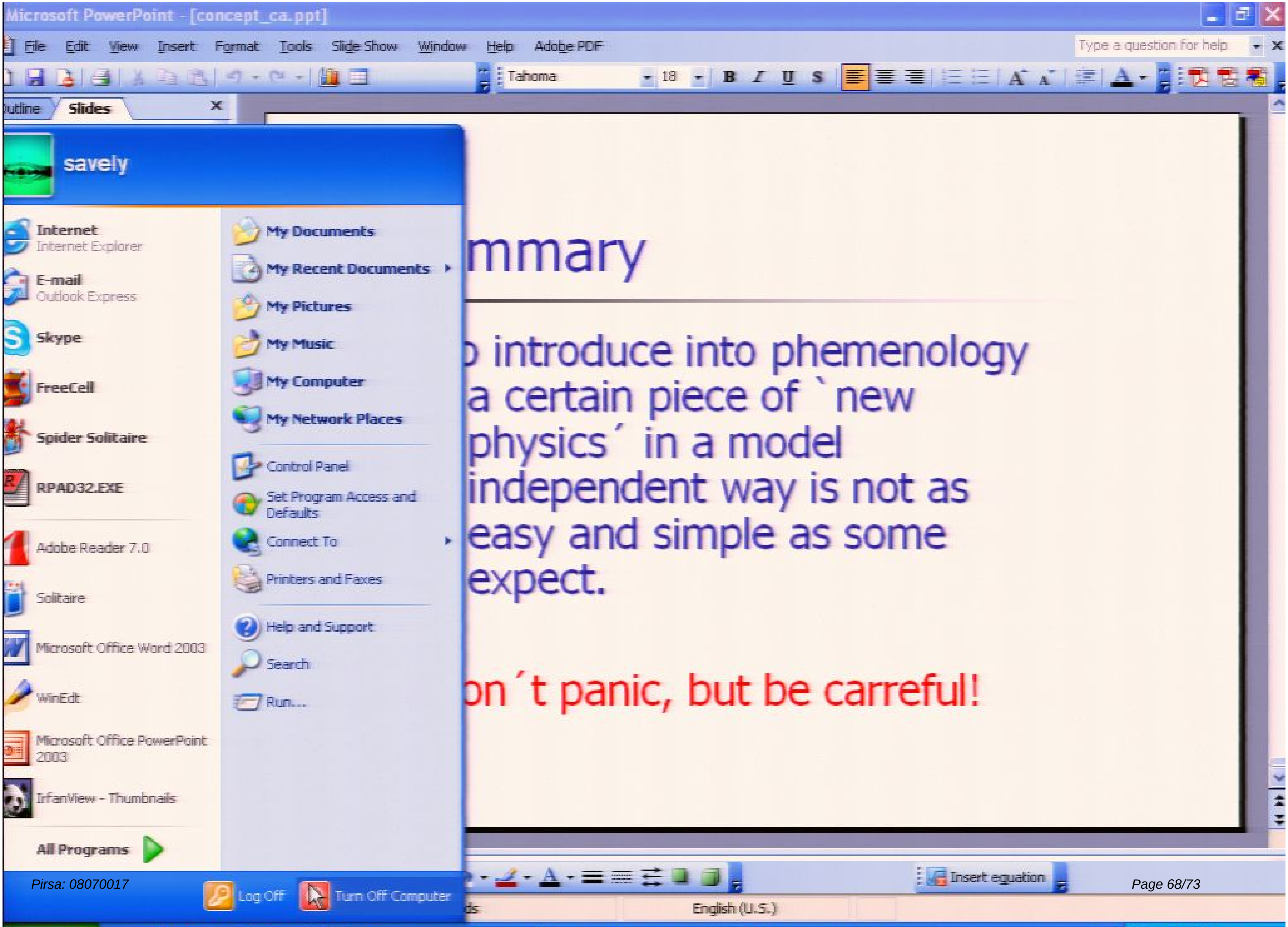
Blends
English (U.S.)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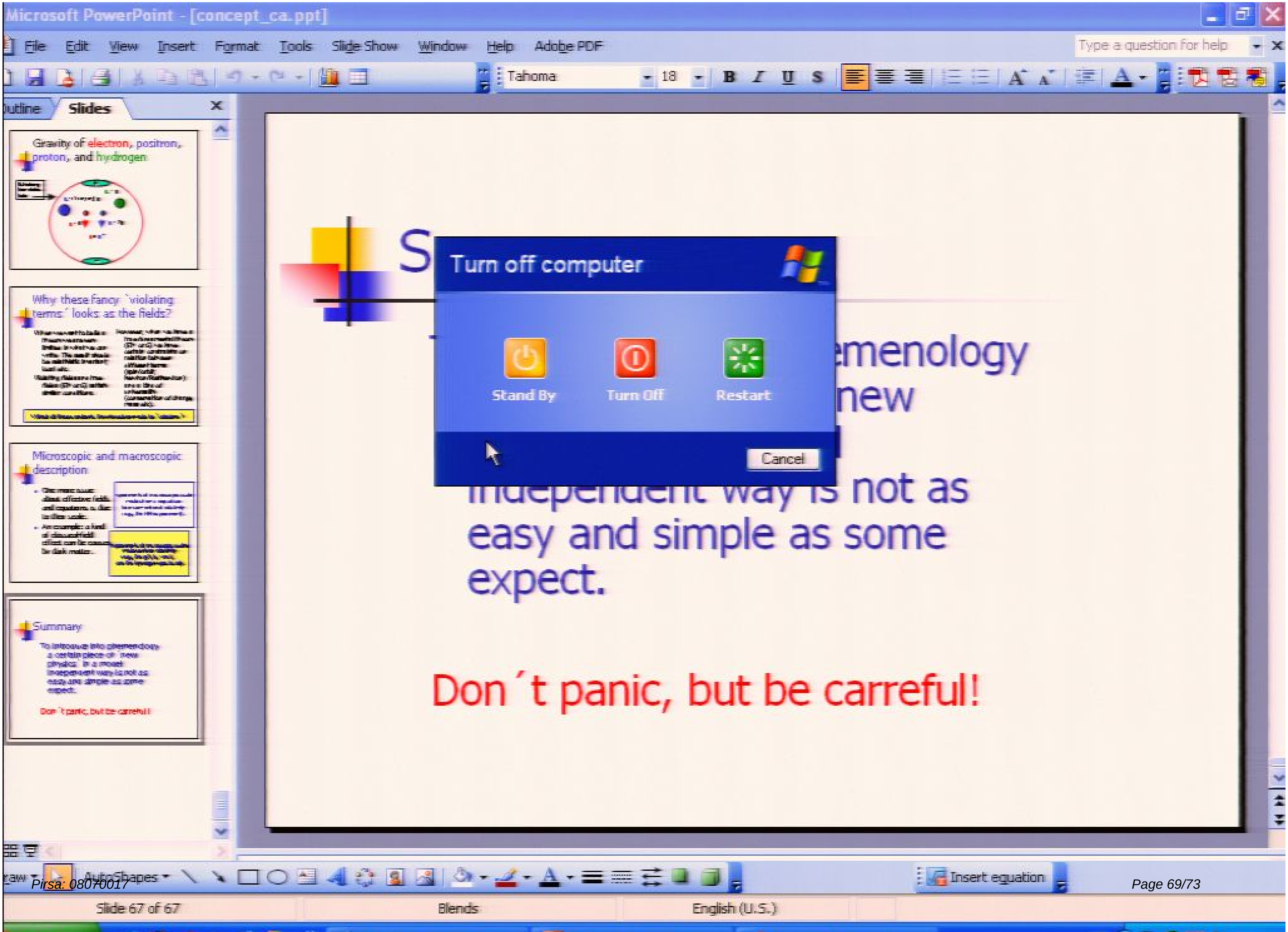
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Slides
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Microscopic and macroscopic description
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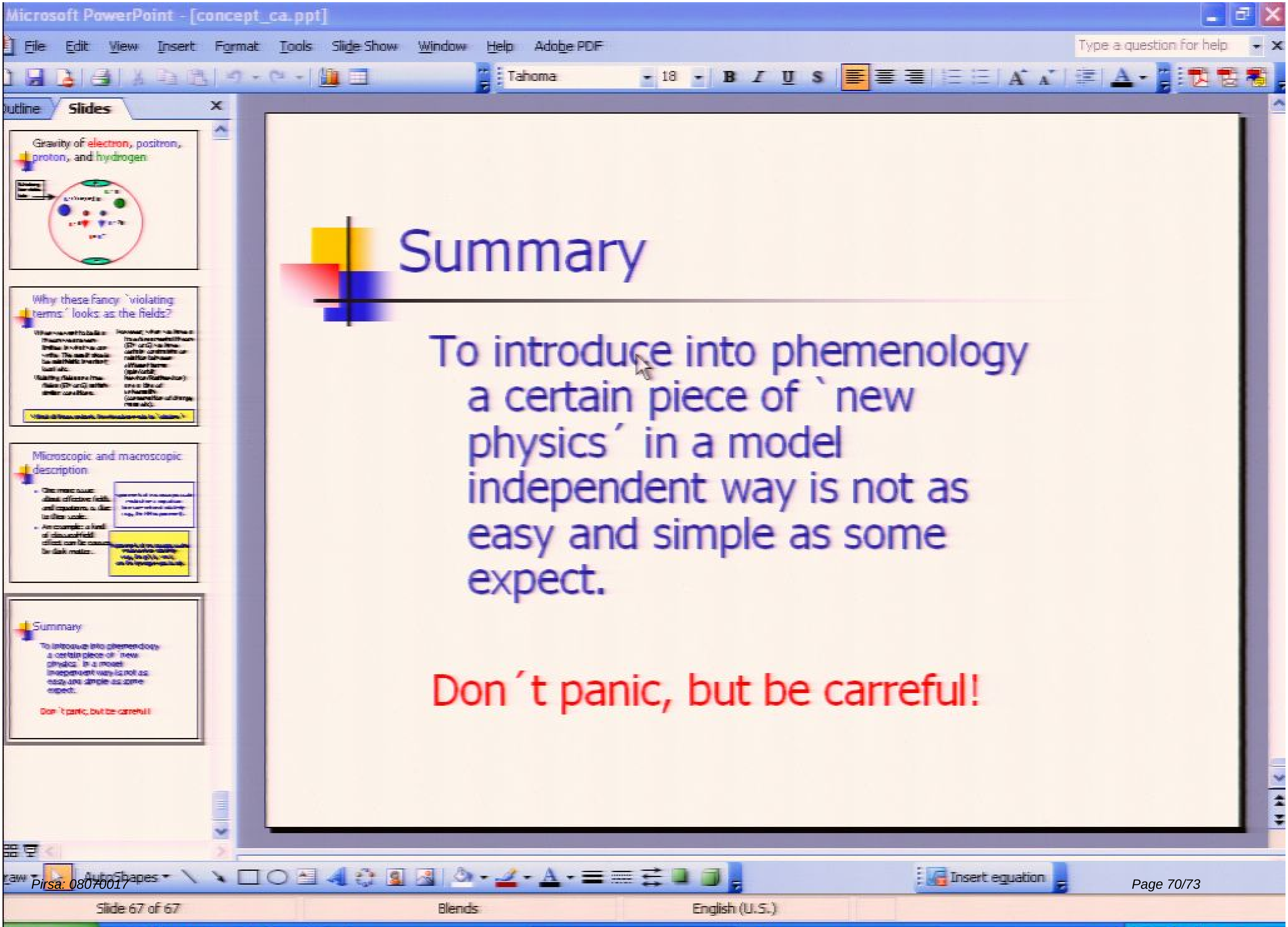
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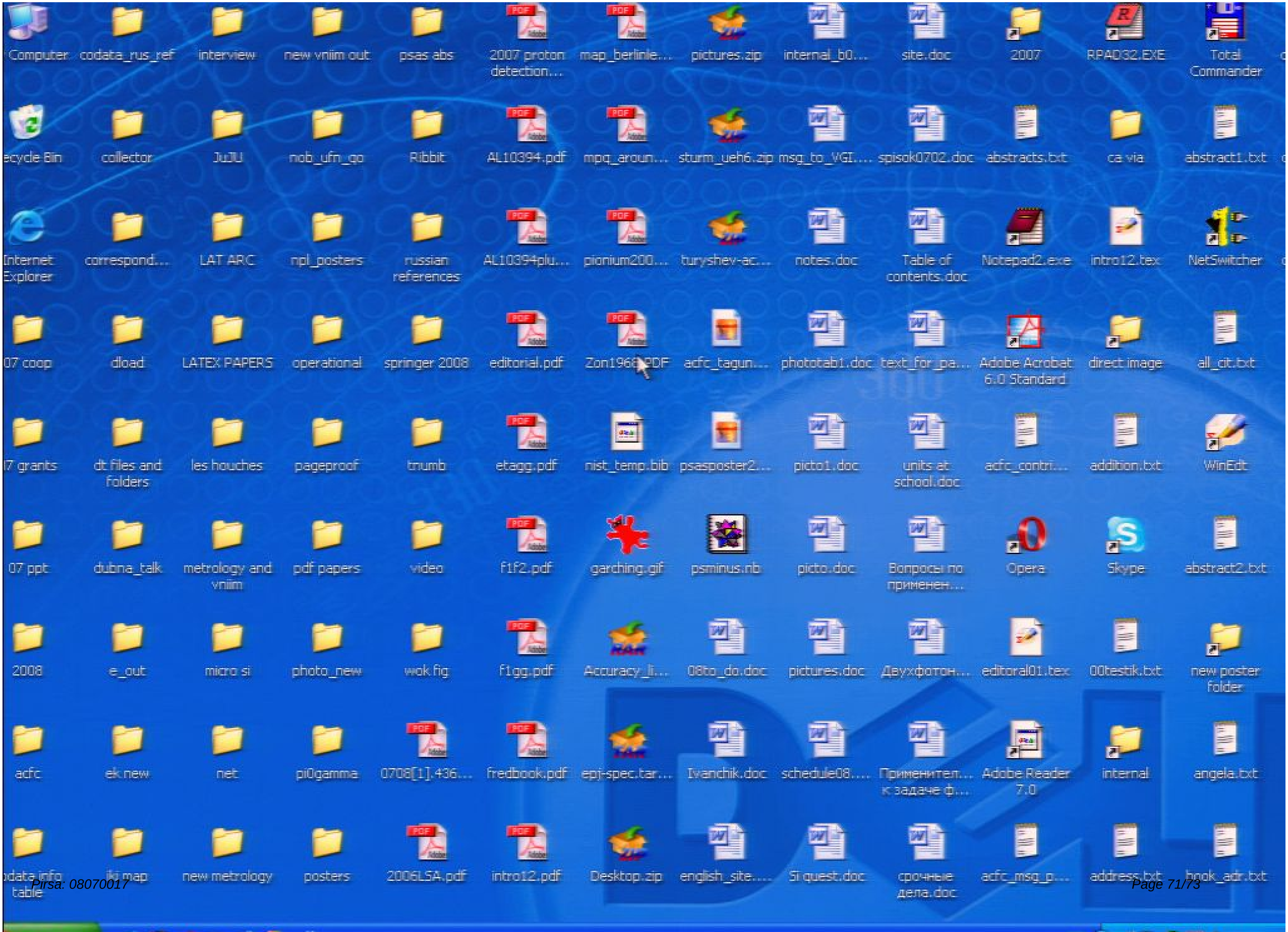
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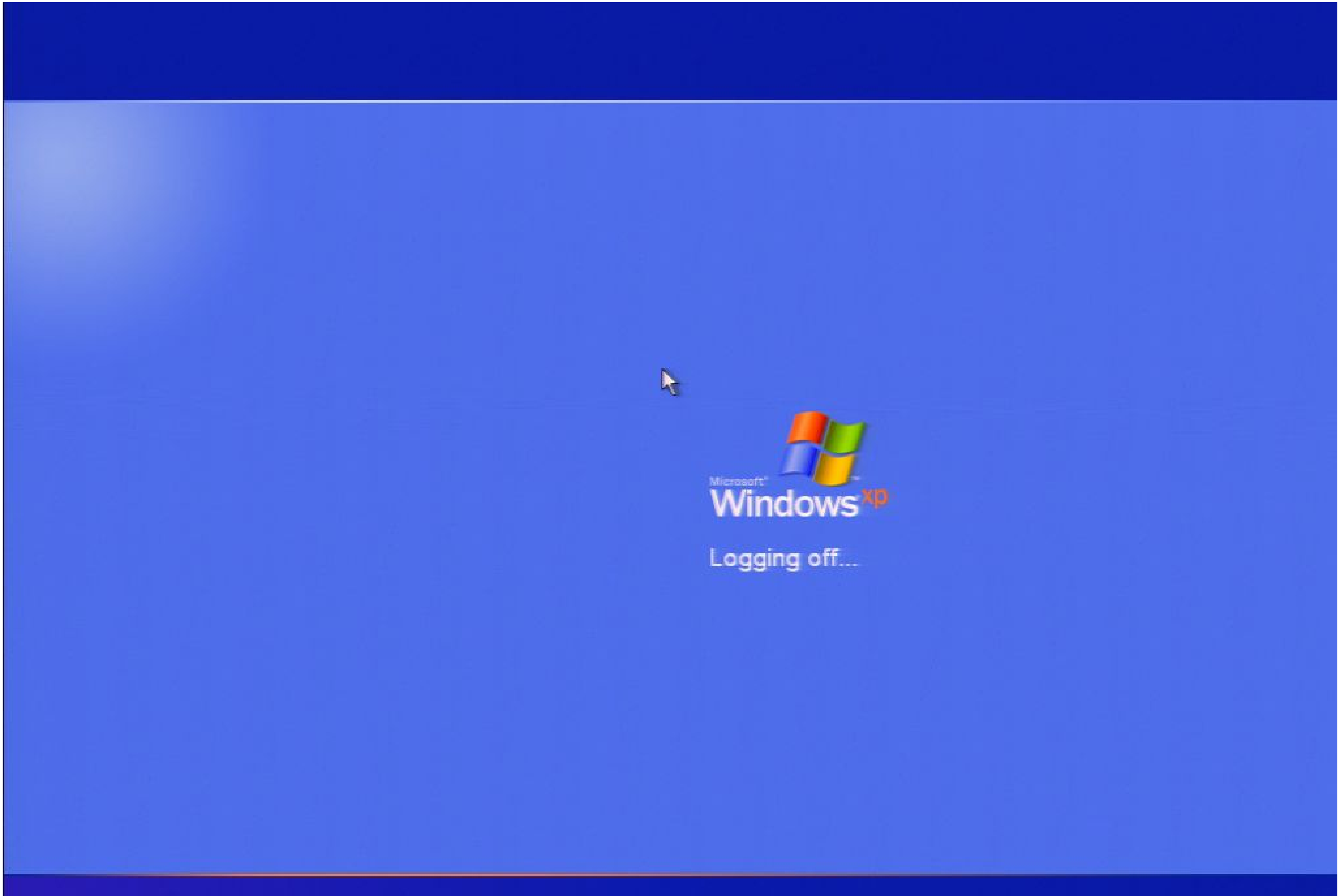
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