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Nieskończenie mała abstrakcja

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Wisła - Malinka
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SYMETRIE

W mechanice kwantowej trzy najważniejsze symetrie związane są z niezmienniczością:

1. na odwrócenie czasu T *(time)*
2. na zmianę ładunku elektrycznego C *(charge)*
3. parzystości P *(parity)*

Ad. 1. Odwrócenie czasu to *puszczenie filmu od tyłu*

Ad. 2. Zmiana ładunku to zastąpienie wszystkich cząstek ich odpowiednikami z antymaterii (na przykład protonu antyprotonem, elektronu pozytonem)

Ad. 3. Zmiana parzystości oznacza obserwację układu w hipotetycznym "trójwymiarowym" lustrze

Wszechświat NIE jest niezmienniczy względem przekształceń T, C, P

W elektrodynamice i chemii istnieje symetria parzystości :
obiekty lewoskrętne i prawoskrętne podlegają tym samym prawom.

W biologii i fizyce słabych oddziaływań symetria parzystości jest złamana:
obiekty lewoskrętne i prawoskrętne zachowują się inaczej.

PARZYSTOŚĆ PRZESTRZENNA *P*

Transformacja parzystości *P* jest dyskretną transformacją współrzędnych czasoprzestrzeni

$$P: \Phi(x,y,z,t) \rightarrow \Phi(-x,-y,-z,t)$$

Transformacje te tworzą dyskretną grupę $Z_2 = \{P, 1\}$

- *1* opisuje transformację tożsamościową, $P \cdot P = 1$

W mechanice kwantowej transformacji tej towarzyszy istnienie operatora parzystości *P*. *P* jest to operatorem unitarnym. Z właściwości grupy wynika, że $P\,\psi_\lambda = \lambda\psi_\lambda$.

Funkcje własne o określonej parzystości spełniają równanie własne $P\,\psi_\lambda = \lambda\psi_\lambda$ dla $\lambda^2 = 1$.

Każdemu polu kwantowemu można więc przypisać wielkość fizyczną, którą nazywa się parzystością. Parzystość może być równa *-1* lub *+1*.

Stany z parzystością *-1* nazywamy stanami *lewoskrętnymi*
a stany z parzystością *+1* stanami *prawoskrętnymi*.

PARZYSTOŚĆ ŁADUNKOWA *C*

W obrazie cząstek elementarnych transformacja *C* zamienia wszystkie cząstki na ich antycząstki.

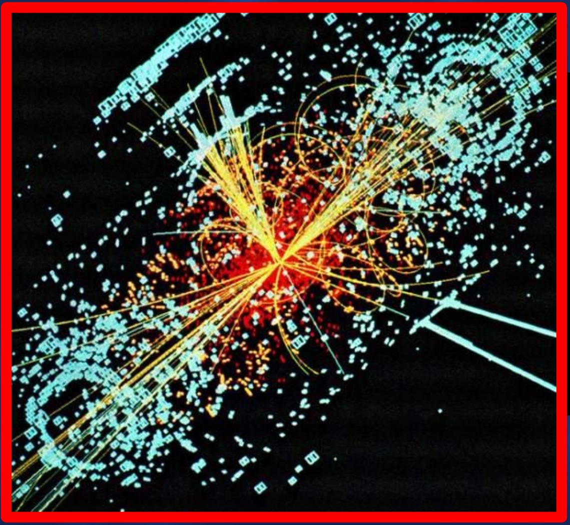
Antymateria, układ antycząstek.
Antycząstki to cząstki elementarne podobne do występujących w zwykłej materii, ale o przeciwnym znaku ładunku elektrycznego oraz wszystkich addytywnych liczb kwantowych np. izospinu, dziwności, liczby barionowej.

W momencie kontaktu antymaterii ze *zwykłą* materią, zachodzi anihilacja.
Energia związana z masą spoczynkową anihilujących cząstek ulega przy tym zamianie na energię promieniowania elektromagnetycznego lub energię kinetyczną lżejszych cząstek.

SPONTANICZNE ŁAMANIE SYMETRII

Nagroda Nobla z fizyki za 2008 roku została przyznana Yoichiro NAMBU z Uniwersytetu w Chicago, Makoto KOBAYASHi z Ośrodka Wysokich Energii w Japonii i Toshihide MASKAWA z Uniwersytetu w Kyoto za ich prace na temat łamania symetrii.

Nambu otrzymał nagrodę za wyjaśnianie **mechanizmu spontanicznego łamania symetrii** a Kobayashi i Maskawa za prace teoretyczne wiążące łamanie symetrii z istnieniem w przyrodzie trzech rodzin kwarków.



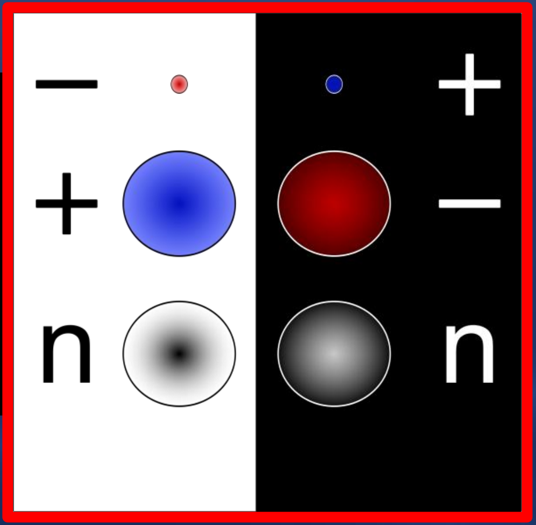
LHCb

Large Hadron Collider beauty

Detektor cząstek elementarnych

Wielki Zderzacz Hadronów

Genewa, CERN.



Zjawisko łamania CP

ma miejsce przy rozpadach kwarków dziwnych (s) *na swoich lżejszych kuzynów*

(Nie)znany elektron

You know, it would be sufficient to really understand the electron
Albert Einstein

Electric Dipol Moment (EDM)
of the electron

The electron that can be told is not the true electron
David Harrison

During an exam (taken from a book):

An abstraction ?

Professor: What is an electron?

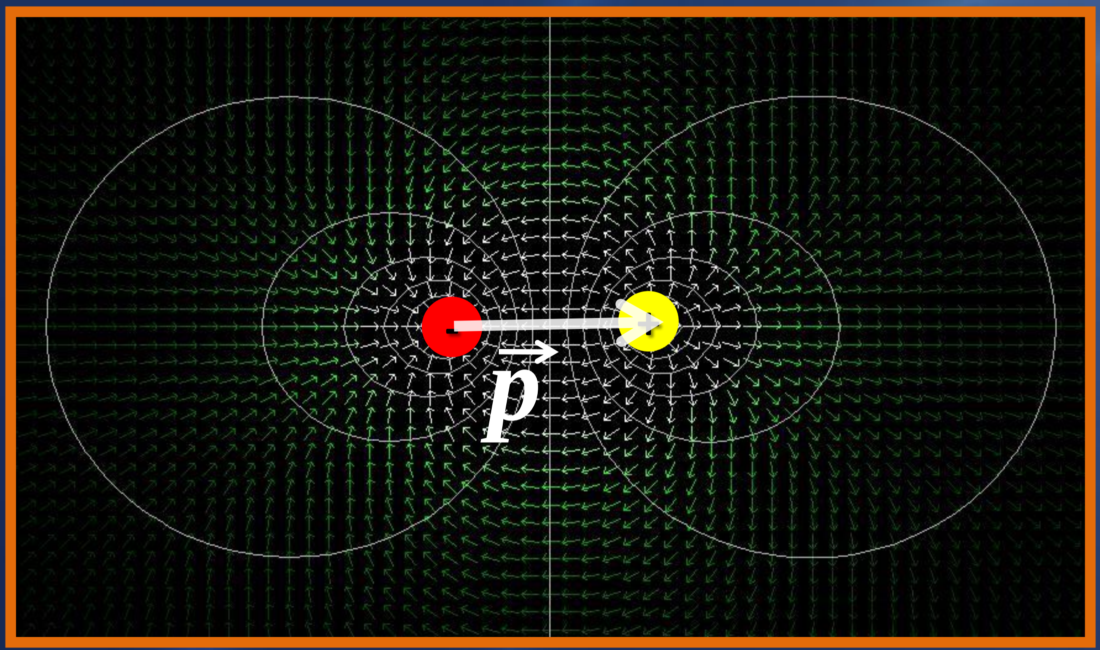
Student: Ah, God damn it! I have forgotten.
And in fact even in the morning I knew it.

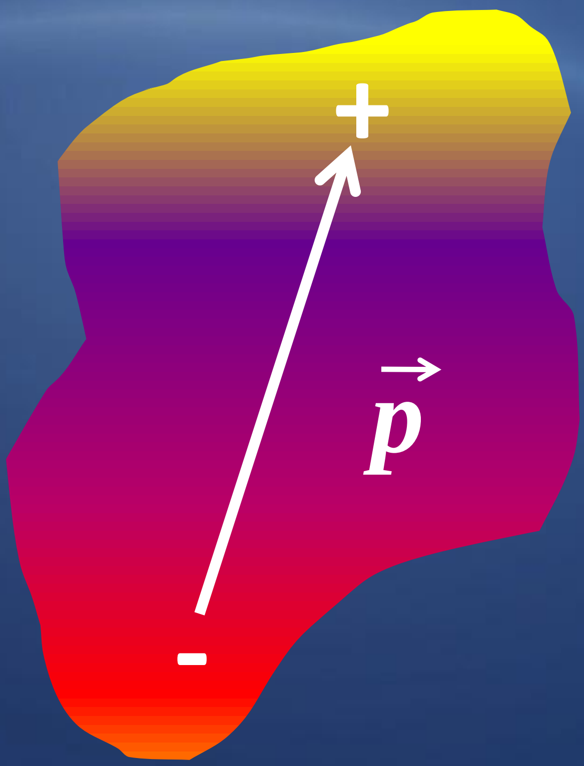
Professor: You should recollect it without fail, Professor said, because you were the unique person who knew what electron was, and you had suddenly forgotten!

Tell me what an electron is and I'll then tell you everything
Somebody

Measuring (almost) zero
Chad ORZEL, *Physics World*, Vol. 22, No.12, December 2009

Inset: Electric Dipol Moment





$$\vec{p} = q \cdot \vec{l}$$

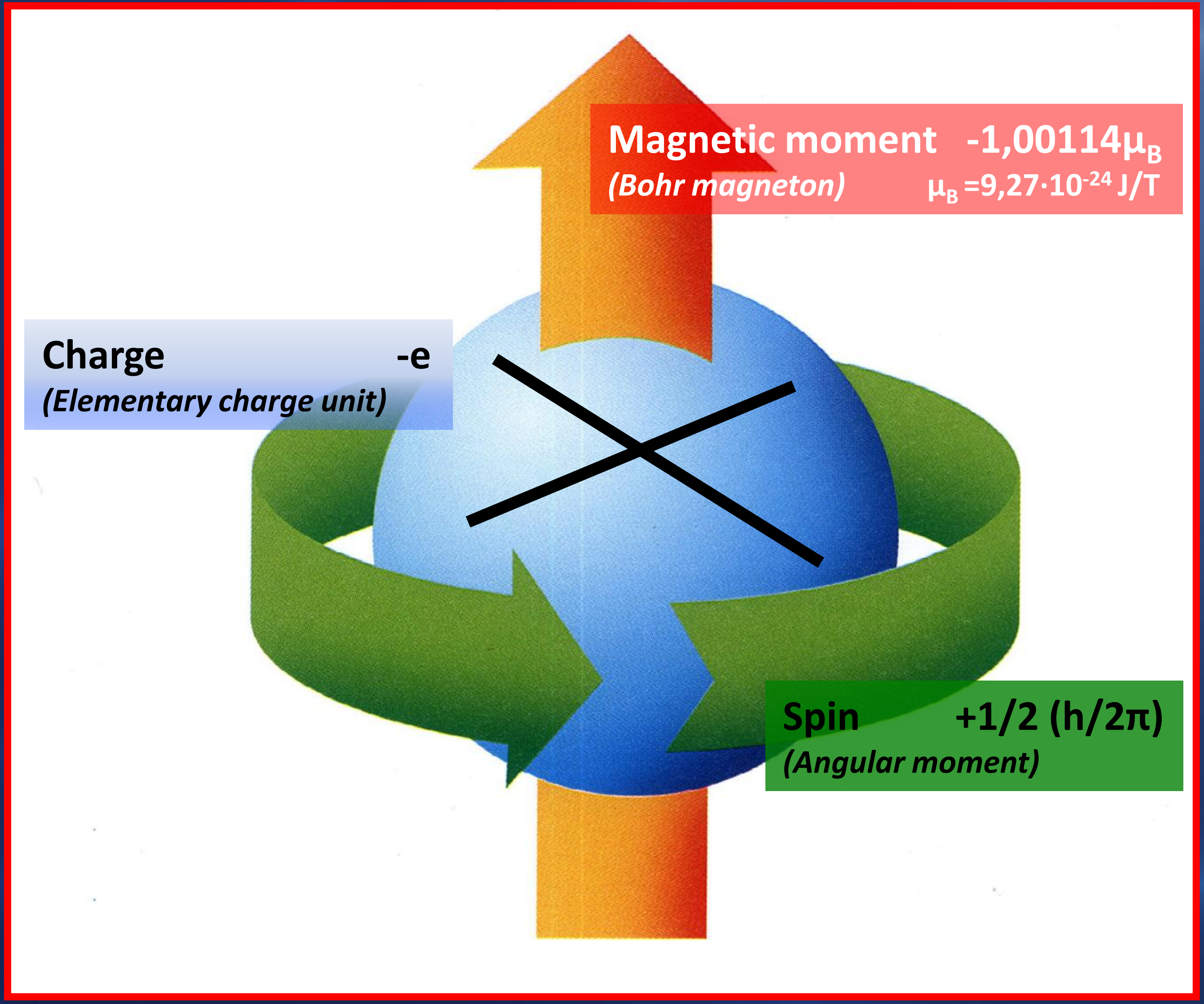
p – dipol moment

q – value of charge

l – distance between the charges - and +

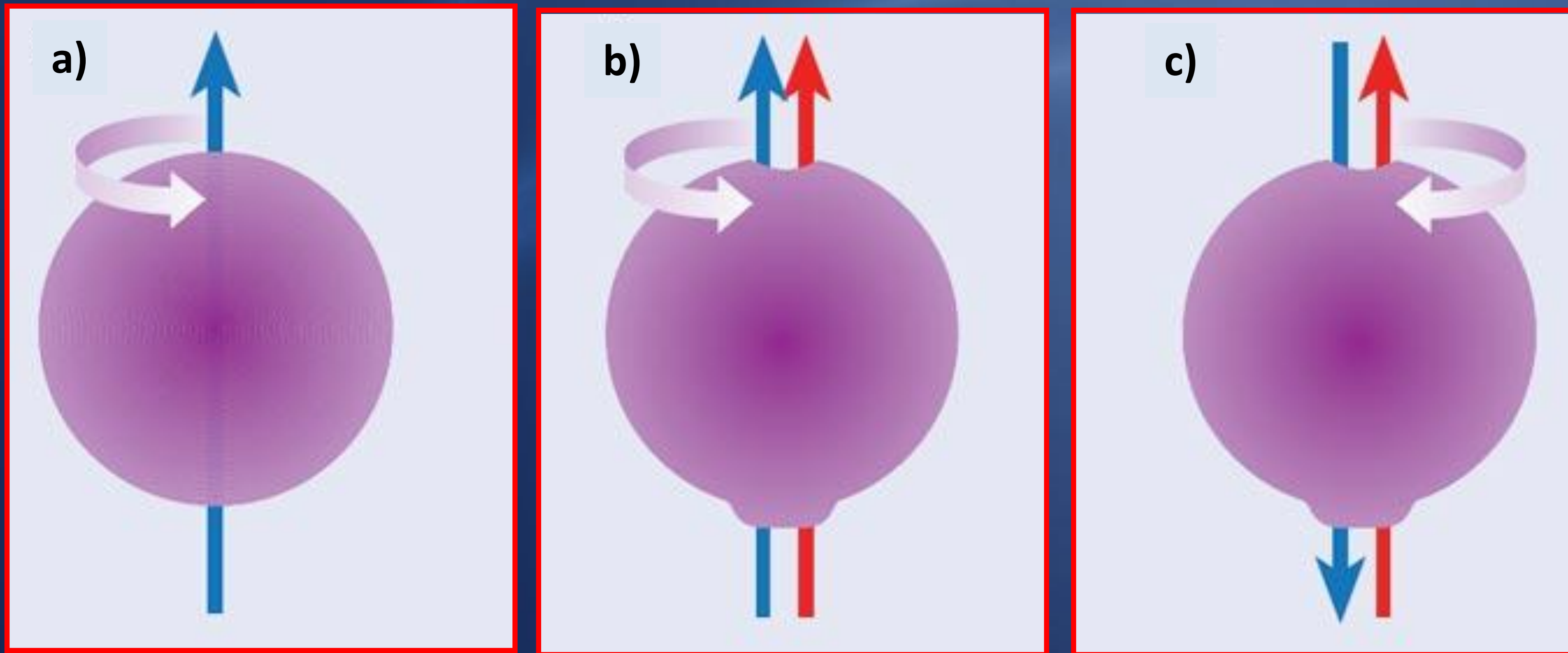
Moment dipol występuje w cząsteczkach w przypadku nierównomiernego rozmieszczenia ładunku dodatniego i ujemnego.

ELECTRON now



Ch. Buchal & D. Bürgier „Peter Grünberg, Nobel preis für Physik", Jülich, 2007

Time - reversal violation with an electron EDM



a)

A spinning charge acts like a loop of current to produce a magnetic dipole moment

b)

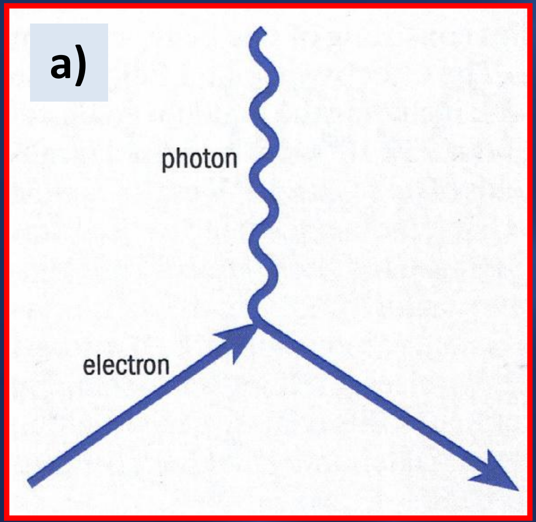
Distorting the electron's charge distribution produces an electric dipole moment in the same direction

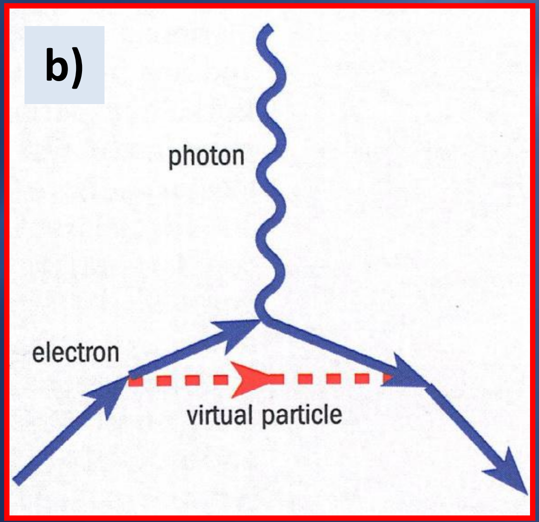
c)

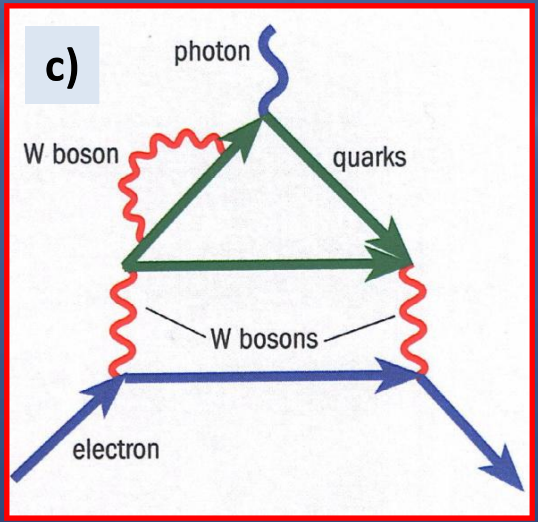
If time reverses, then the charge spins in the opposite direction. This flips the magnetic dipole but not the electric one, so the two dipoles are no longer aligned – violating time reversal symmetry and preventing the electron from having a permanent electric dipole moment in the basic Standard Model of particle physics.

Chad ORZEL, *Physics World*, Vol. 22, No.12, December 2009

Time - reversal violation with an electron EDM







a)

The electron-field interaction is described in terms "Feynman diagrams", pictures showing as the electron interacts with its environment. Time flows from left to right, so the illustration shows an electron moving through space, then absorbing or emitting a photon from the electromagnetic field and changing its direction.

b)

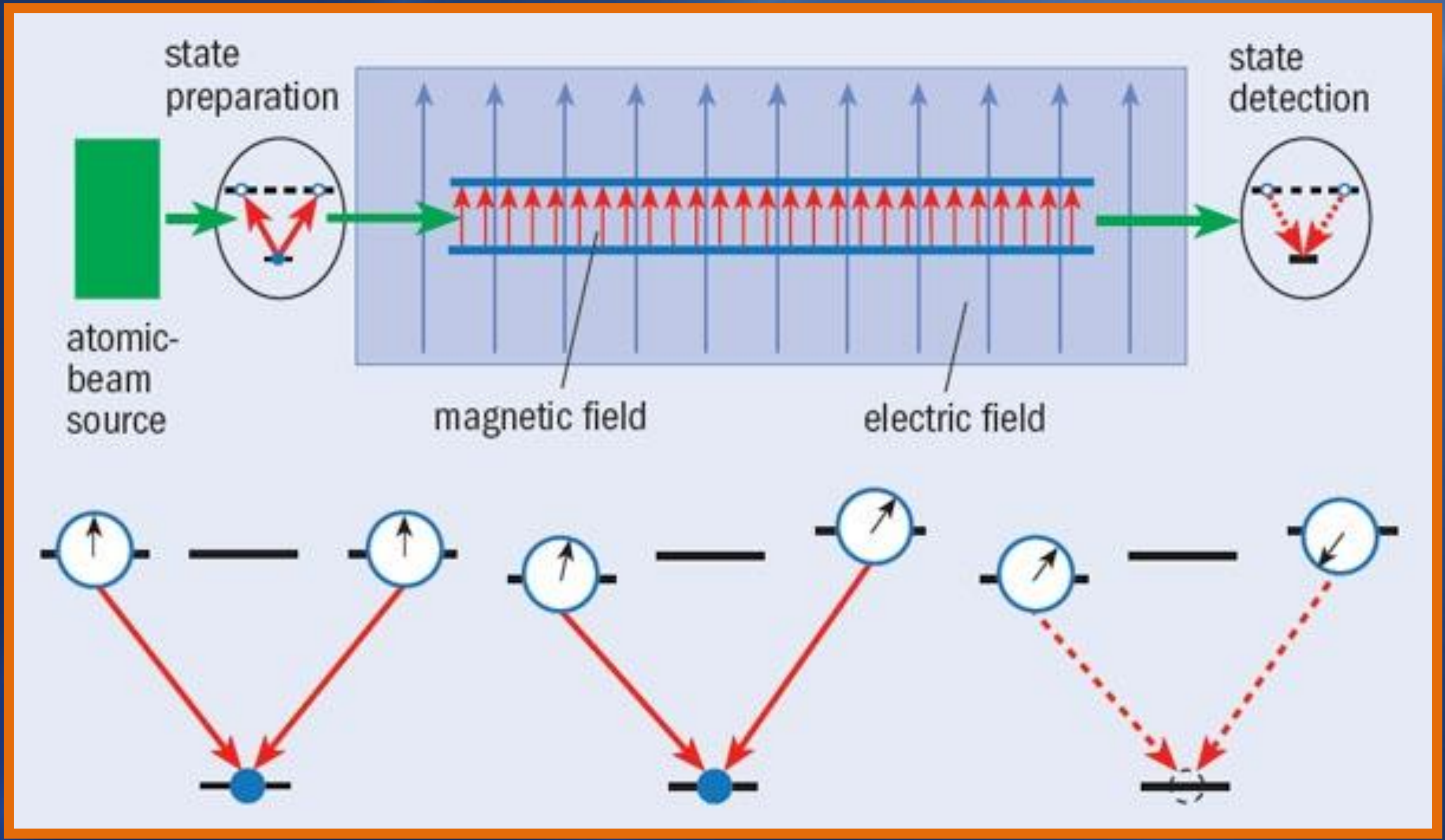
The most important type of the diagram. The electron moves through space as before, but before interacting with the photon, it emits a „virtual" particle, which it re-absorbs after interacting with the photon. The virtual particle can be just about anything that interacts with an electron, provided it disappears quickly enough that it cannot be detected directly. Such "loop„ diagrams change the way that the electron interacts with light, and an electron electric dipole moment (EDM) is the result. Most theories of physics beyond the Standard Model predict the existence of new particle that can create an EDM through simple diagram like that shown in Figure b).

c)

Within the Standard Model, it is much more difficult to generate an EDM. The simplest diagram that produces an EDM involves three bosons (red lines) and a part of quarks (green lines) in addition to the photon and electron. Such a complicated process is extremely unlikely, and thus produces a very small EDM.

Chad ORZEL, *Physics World*, Vol. 22, No.12, December 2009

Interferometric detection of an EDM shift



The basic structure of a beam-based electric dipole moment (EDM) experiment.

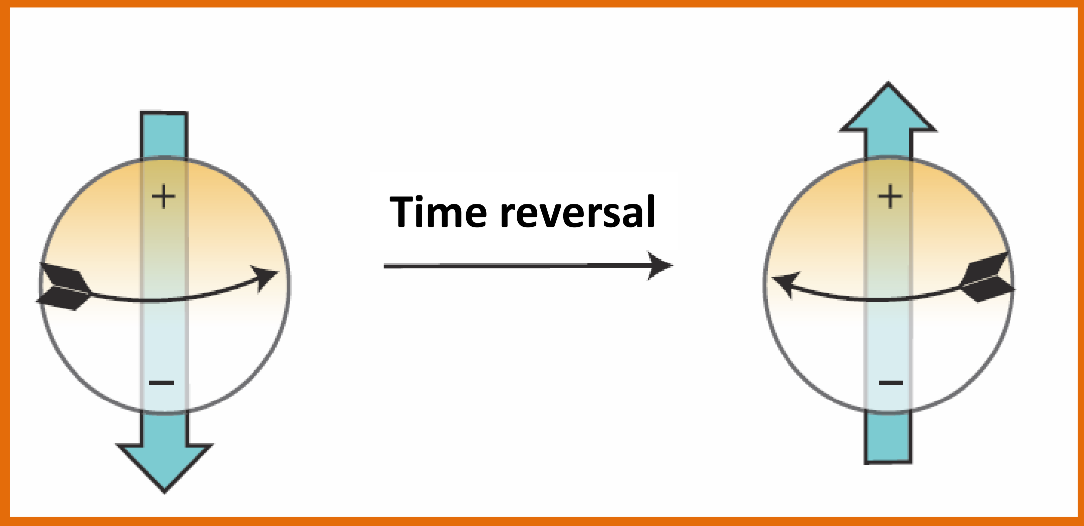
Chad ORZEL, *Physics World*, Vol. 22, No.12, December 2009

nature materials
ARTICLES
PUBLISHED ONLINE: 18 JULY 2010 | DOI:10.1038/NMAT2799

A multiferroic material to search for the permanent electric dipole moment of the electron

K. Z. Rushchanskii[1], S. Kamba[2], V. Goian[2], P. Vaněk[2], M. Savinov[2], J. Prokleška[3], D. Nuzhnyy[2], K. Knížek[2], F. Laufek[4], S. Eckel[5], S. K. Lamoreaux[5], A. O. Sushkov[5], M. Ležaić[1] and N. A. Spaldin[6]*

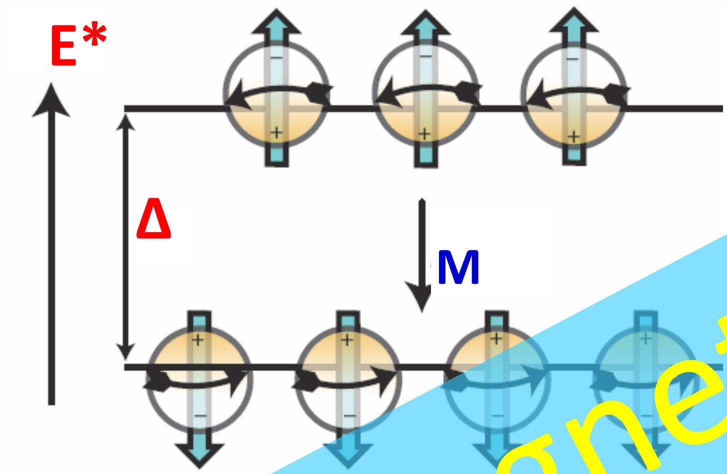
Illustration that an electron with an EDM violates time-reversal symmetry



Both the EDM (+ and - symbols; orange shading) and magnetic moment (blue arrow) of the electron lie along the same axis as the electron spin (black arrow).

The operation of time reversal reverses the magnetic moment but does not affect the EDM. Therefore, an electron with a non-zero EDM violates time-reversal symmetry.

Schematic of the physics underlying the experiment to search for the electron EDM



The magnetoelectriceffect

1. As spin is the only intrinsic vector associated with the electron, a non-vanishing electron EDM is either parallel or antiparallel to its spin and hence its magnetic moment.

2. The energy of electrons with E
than that for electrons with anti-p

$$P_i = \sum \alpha_{ij} H_j + \sum \beta_{ijk} H_j H_{kj} + \; ...$$

3. When an electric field - which
parallel and antiparallel to it - is a
electron populations generates a

$$M_i = \sum \alpha_{ij} E_j + \sum \beta_{ijk} E_j E_{kj} + \; ...$$

4. When the electric field is reversed there is a magnetization reversal, ΔM, which can be detected using a sensitive magnetometer.

The following material specifications will enable a sensitive EDM search to be mounted:

1. The material should be ferroelectric, with a large electric polarization, and switchable at liquid-He temperature.

2. There should be a high concentration of heavy ions with local magnetic moments that remain paramagnetic at liquid-He temperature; both long-range order and freezing into a glassy state must be avoided.

3. The local environment at each magnetic ion should be strongly modified by the ferroelectric switching.

4. The sample should be macroscopic.

Superconducting Quantum Interference Device
Sensivity $5 \cdot 10^{-18}$ T

With these materials properties, and optimal SQUID noise levels, the projected experimental sensitivity is $d_e = 10^{-28}$ [e·cm] after ten days of averaging

ładunek elektronu $e = 1.6\ 10^{-19}$ [C]

To search for the electron EDM a specific material is nedeed

$EuTiO_3$
$BaTiO_3$

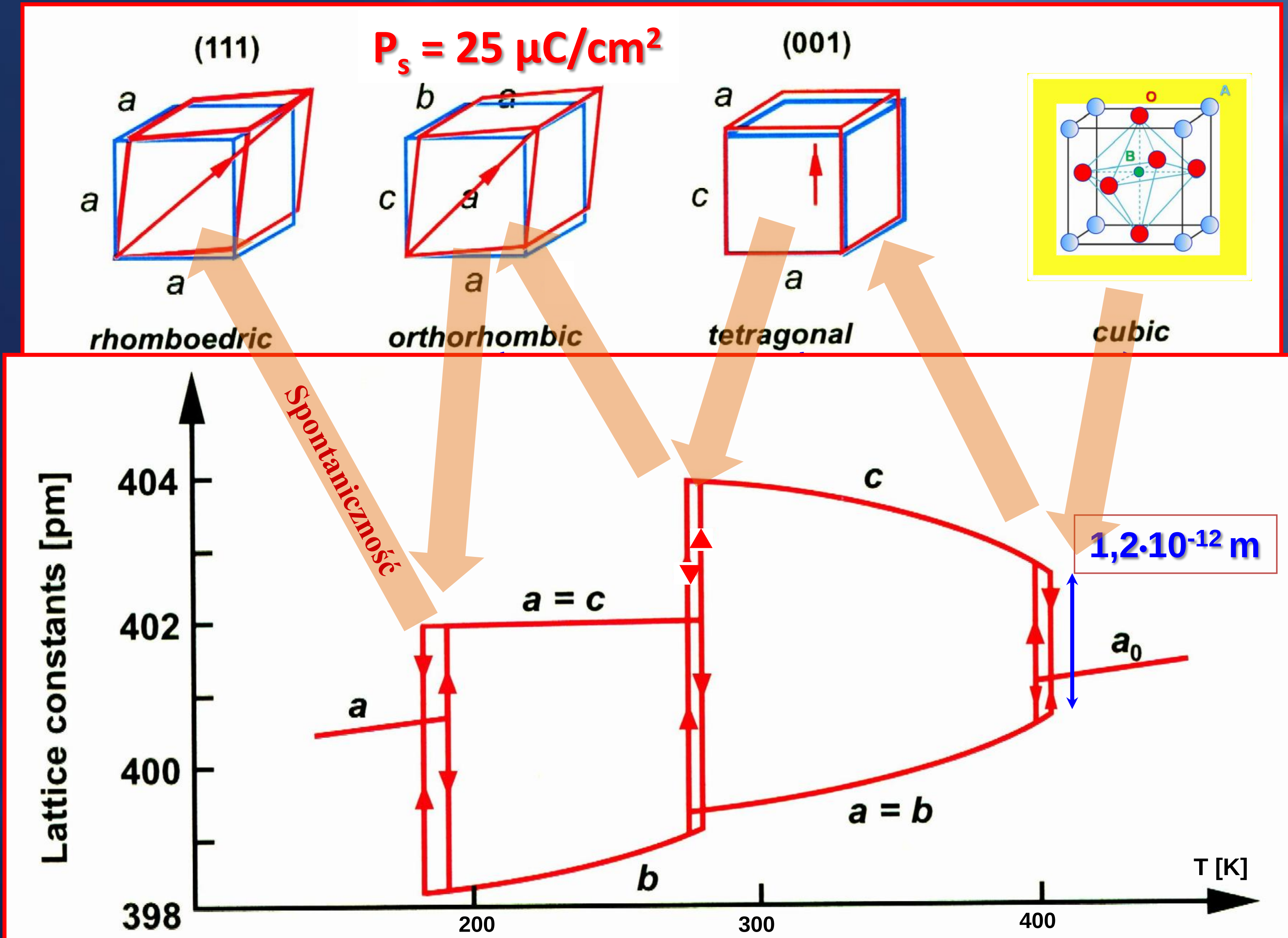
The lattice parameter of $EuTiO_3$ is 3.905 Å notably smaller than that of $BaTiO_3$.
It is not ferroelectric, but has a large dielectric constant (400) at low temperature indicative of proximity to a ferroelectric phase transition; indeed, it has recently been reported to be a quantum paraelectric.

The Eu^{+2} ion has seven unpaired localized 4f electrons, resulting in a large spin magnetization of $7\mu_B$, and $EuTiO_3$ is an antiferromagnet with a low Néel temperature of 5.3 K .

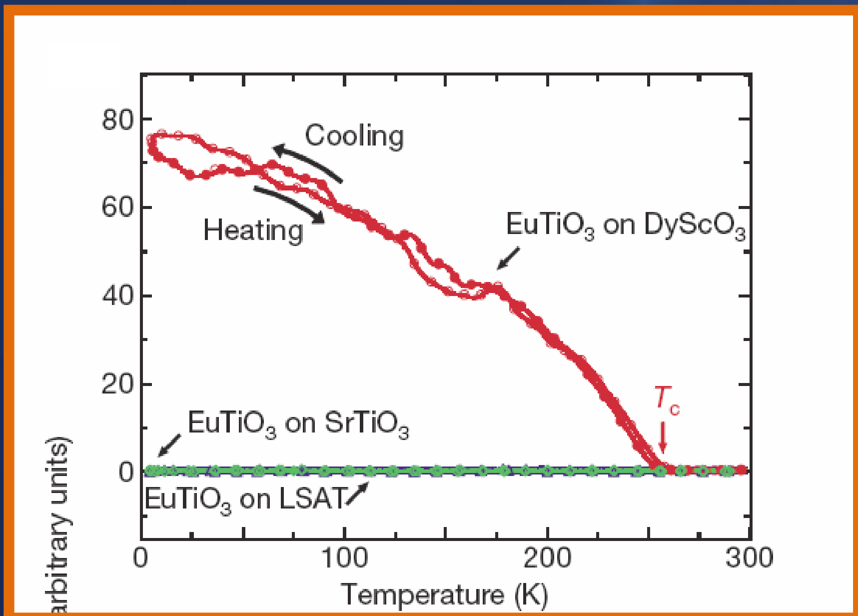
A hypothesis is that by alloying Ba on the A site of $EuTiO_3$ the magnetic ordering temperature will be suppressed through dilution, and the tendency to ferroelectricity will be increased through the expansion of the lattice constant.

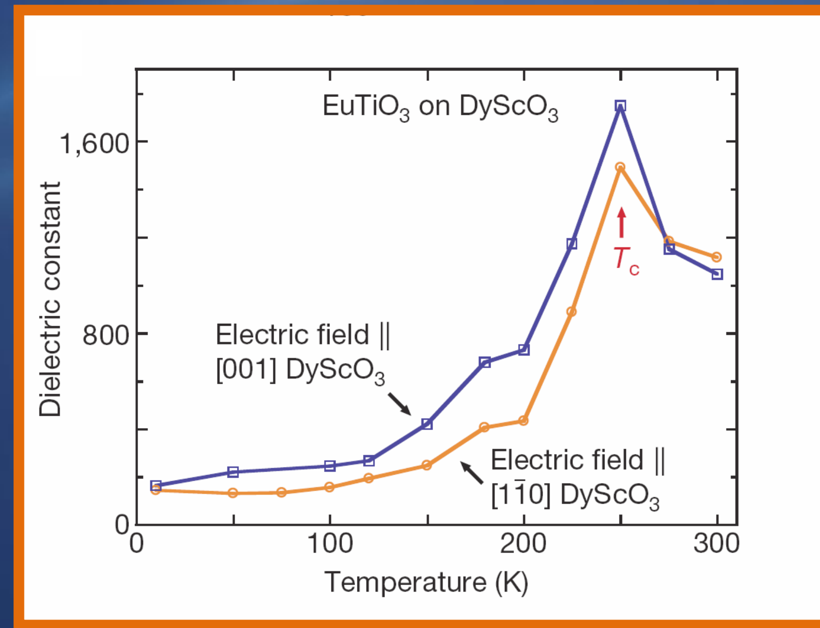
The magnetic ordering temperature is sufficiently low while the ferroelectric polarization and the concentration of magnetic ions remain sufficiently large.

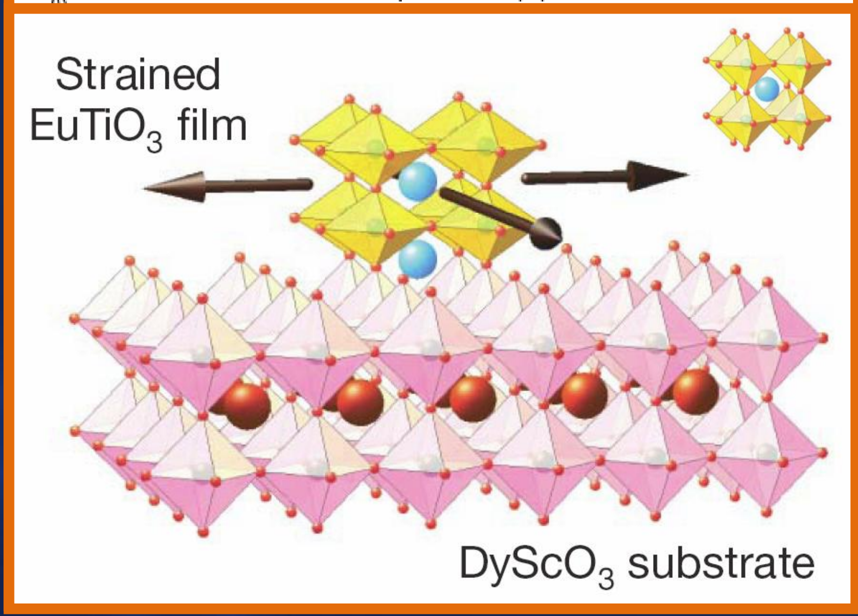
Phase transitions in barium titanate $BaTiO_3$



Phase transitions in europe titanate $EuTiO_3$







$EuTiO_3$, was predicted to exhibit strong ferromagnetism with spontaneous magnetization, 7 Bohr magnetons per Eu and strong ferroelectricity with spontaneous polarization 10 *μC/cm²* *simultaneously* under large biaxial compressive strain. These values are orders of magnitude higher than those of any known ferroelectric ferromagnet and rival the best materials that are solely ferroelectric or ferromagnetic.

Thickness of the $EuTiO_3$ film is of the order of 20 nm

The best candidate $Eu_{0.5}Ba_{0.5}TiO_3$?

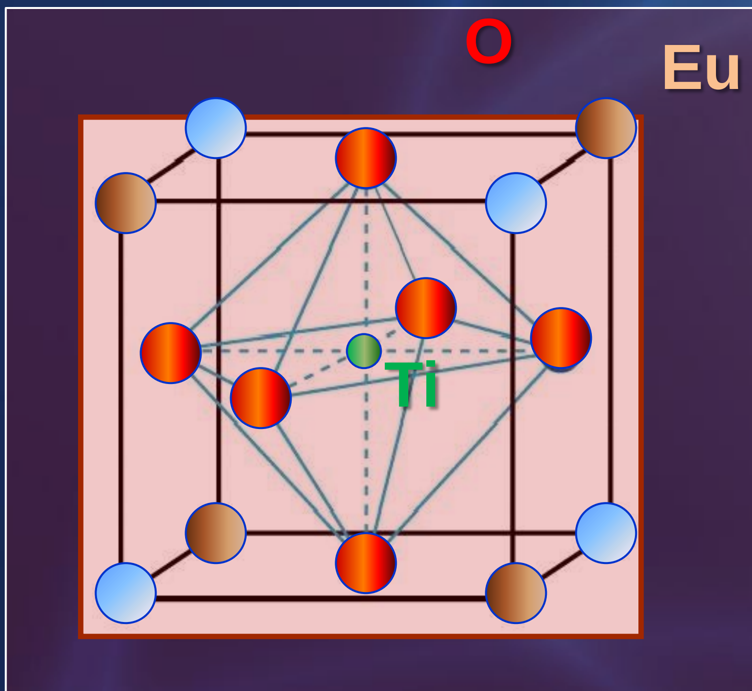
Eu
Ionic radius: 0.95 Å

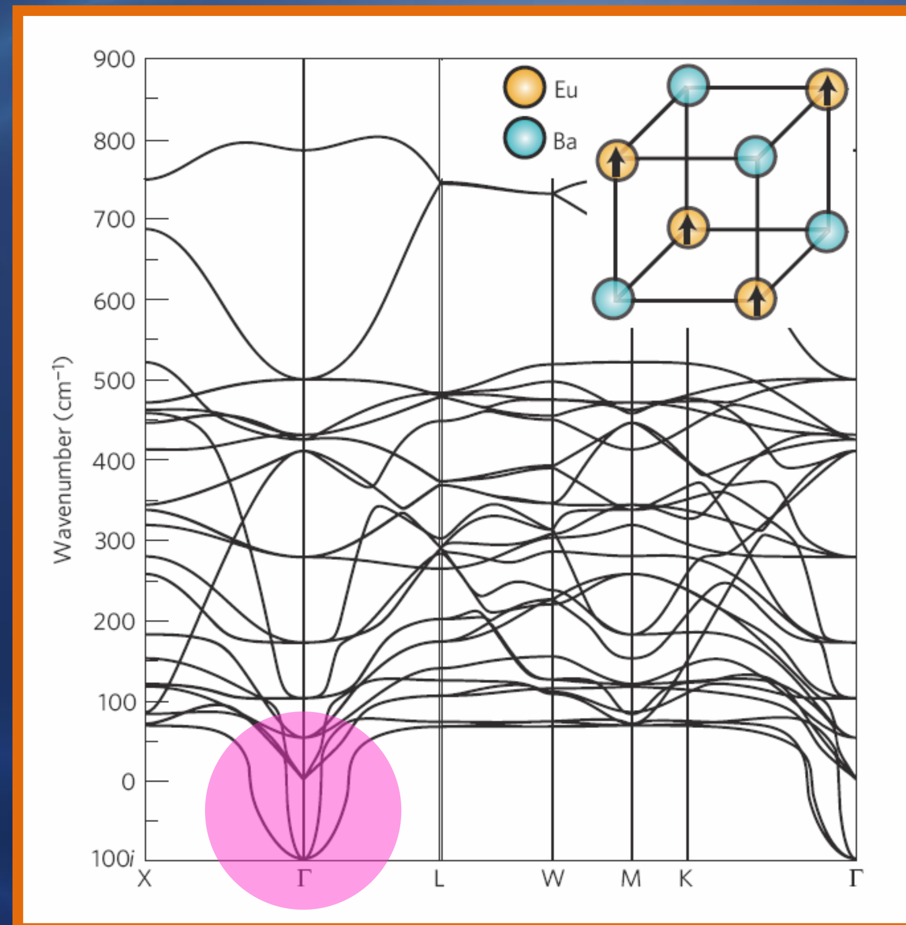
Ba
Ionic radius: 1,35 Å

Ti
Ionic radius: 0.68 Å

O
Ionic radius: 1.40 Å

Calculated phonon dispersion of ferromagnetic $Eu_{0.5}Ba_{0.5}TiO_3$ in its high-symmetry reference structure with pseudo-cubic lattice constant a_0 =3,95 Å.





The imaginary-frequency polar phonon at *Γ* indicates a structural instability to a ferroelectric phase.

The inset shows the supercell of the ferromagnetic $Eu_{0.5}Ba_{0.5}TiO_3$ ordered alloy used in our calculations. The Ti and O ions are omitted for clarity; arrows represent the Eu magnetic moments.

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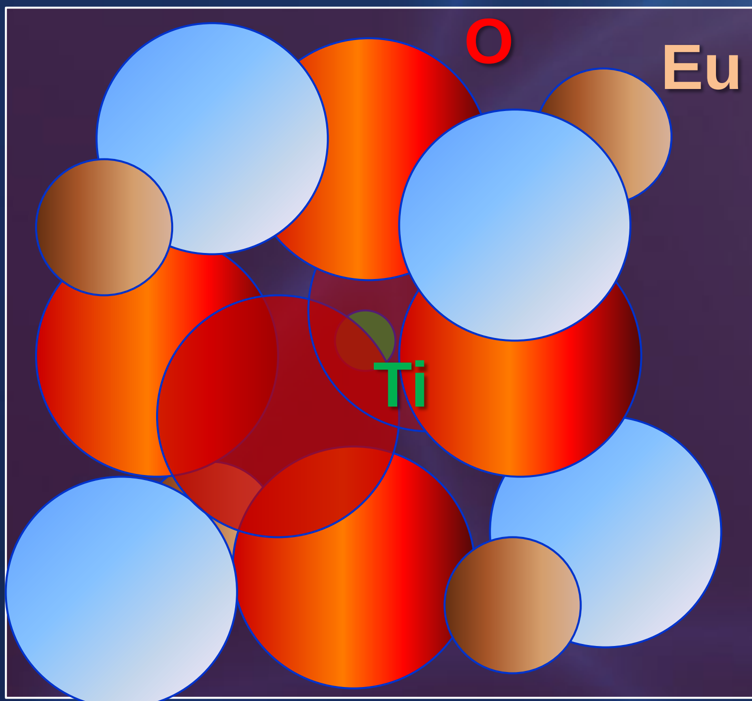

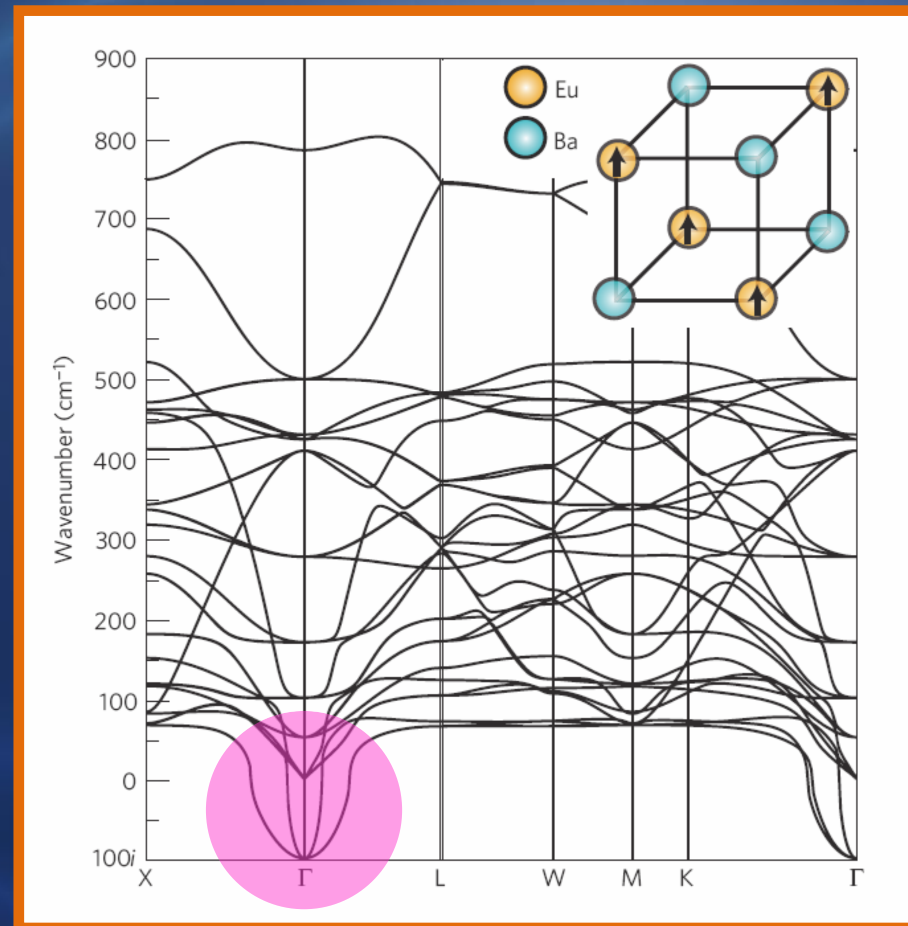

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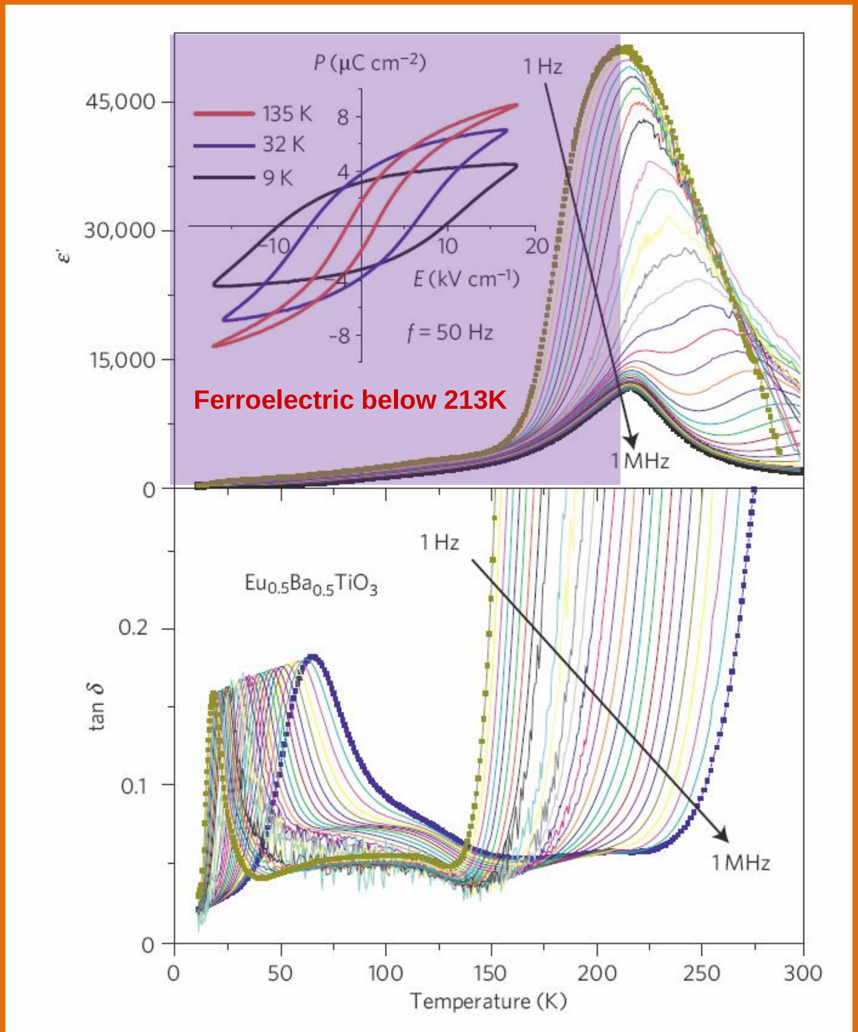
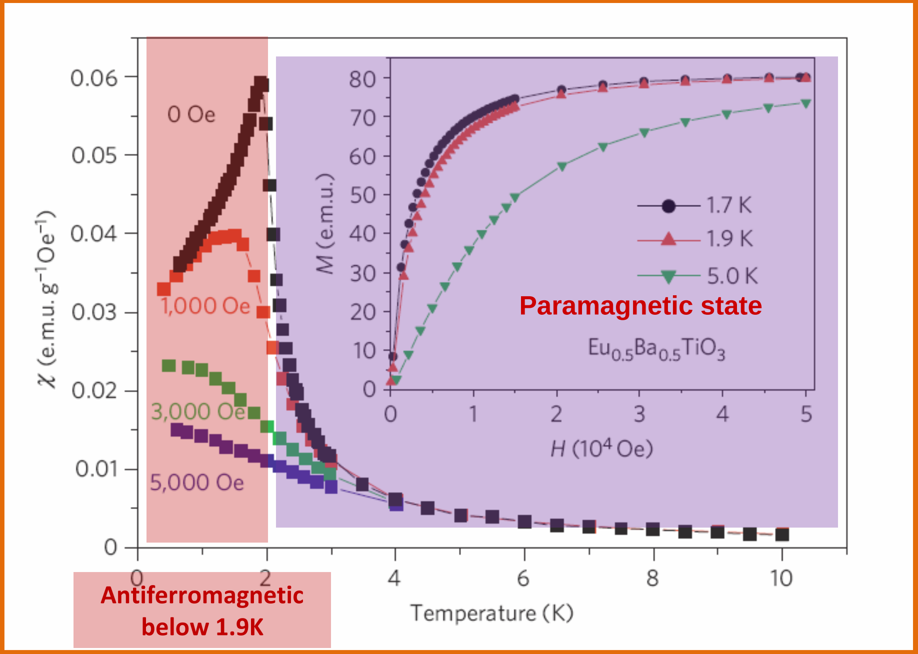
$Eu_{0.5}Ba_{0.5}TiO_3$ ceramics





Temperature dependence of ac magnetic susceptibility, at various static magnetic fields and a frequency of 214 Hz.

The inset shows magnetization curves at various temperatures. We note that no hysteresis in magnetization was observed.

Temperature dependence of permittivity and dielectric loss in $Eu_{0.5}Ba_{0.5}TiO_3$ ceramics. The arrows indicate the direction of increasing frequency and the colours are for clarity to assist the eye in distinguishing the lines.
The inset shows ferroelectric hysteresis loops measured at three temperatures and 50 Hz.

In summary:

$Eu_{0.5}Ba_{0.5}TiO_3$ ceramics confirmed their desirable ferroelectric polarization and absence of magnetic ordering above 1.9 K.

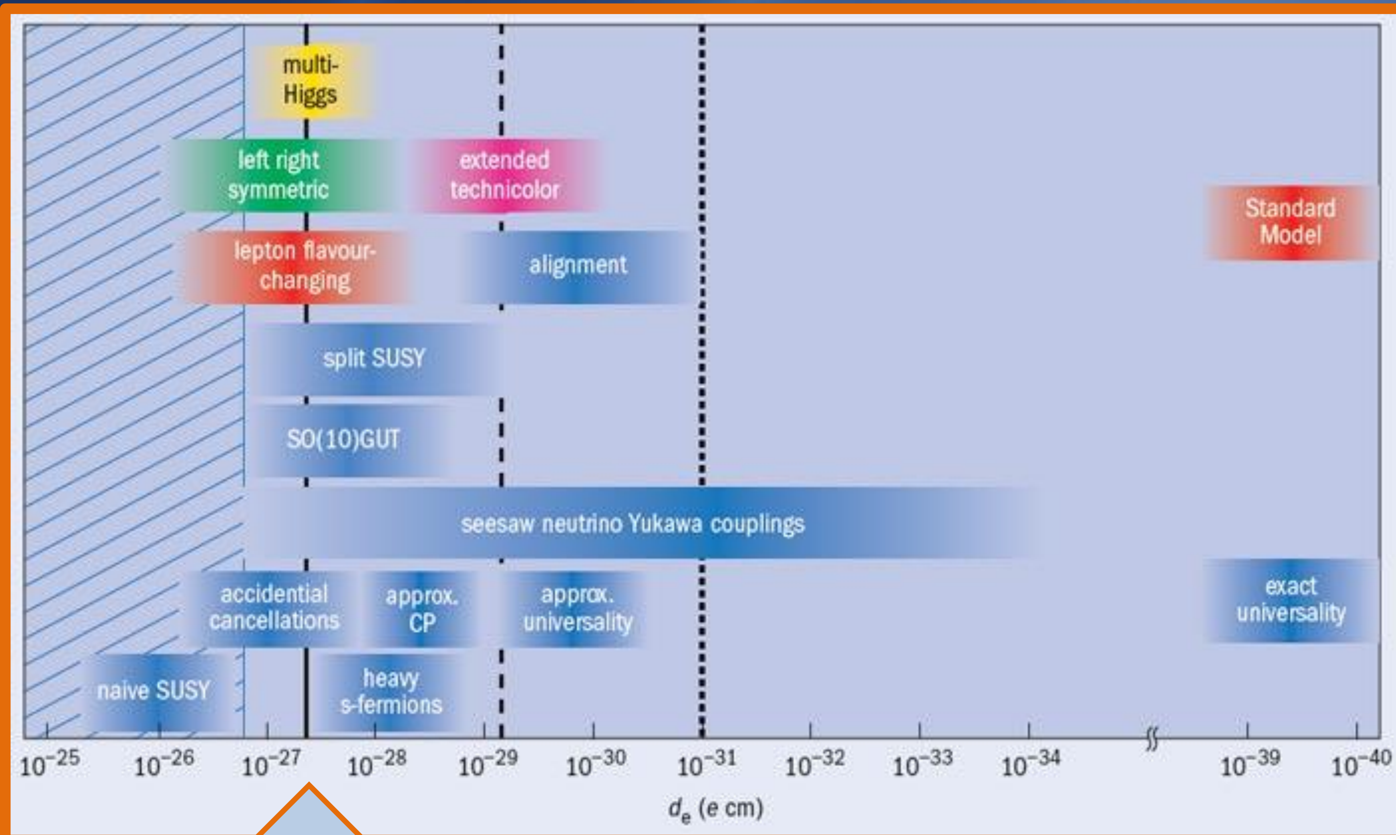
The search for the permanent dipole moment of the electron using $Eu_{0.5}Ba_{0.5}TiO_3$ is now underway. Initial measurements have already achieved an EDM upper limit of $5 \cdot 10^{-23}$ e·cm, which is within a factor of 10 of the *current record* with a solid-state-based EDM search.

A number of systematic effects that may mask the EDM signal is being controlled. The primary error originates from ferroelectric hysteresis-induced heating of the samples during polarization reversal. This heating gives rise to a change in magnetic susceptibility, which, in a non-zero external magnetic field, leads to an undesirable sample magnetization response. We are working to control the absolute magnetic field at the location of the samples to the 0.1 μG level .

(Dla Ziemi indukcja magnetyczna B = 30μT = 3 10^{-3}G = 3mG = 3000 μG)

Sensitivity of $1 \cdot 10^{-28}$ e·cm should be achievable

Electron EDM predictions of various theories beyond the Standard Model



Experiments performed in …02 at th… niversity of California, Berkeley, showed that **if the electric** … **(EDM)** … **sts, the** … **must be smaller than 10^{-27} *e* cm.** … **aive su…-symmetry" (naive SUSY) theory.**

Current maximum sensitivity

Next generation of cold-molecule experiments

Yale/Harvard experiment using thorium monoxide ThO

Chad ORZEL, *Physics World*, Vol. 22, No.12, December 2009

Czyż eEDM nie jest *nieskończenie małą abstrakcją*?







Czyż eEDM nie jest *nieskończenie małą abstrakcją*?