Electromagnetism is still fundamental science.

Recent developments in clarifying the theoretical foundations of electromagnetism.

Alberto Favaro

Department of Physics,
Imperial College London, UK.

March 21, 2011

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- Today, many theories of spacetime. EM testing ground for multiple theories, as little assumed about spacetime.
- Charge conservation experiments $\Rightarrow$ inhomogeneous Maxwell's equations. Closed magnetic lines experiments $\Rightarrow$ homogeneous Maxwell's equations.
- EM response of spacetime: linearity, zero birefringence, electric-magnetic duality measurements.

Less is more*.

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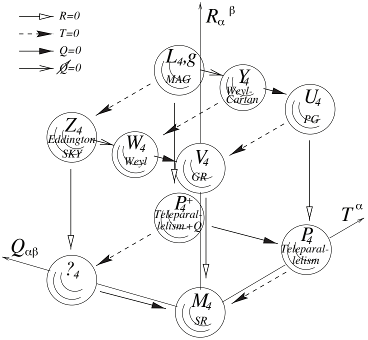

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Figure: Hehl and Obukhov (Birkhäuser, 2003).

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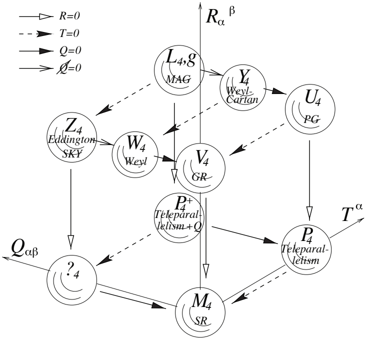

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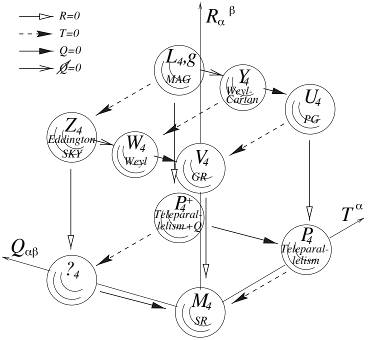

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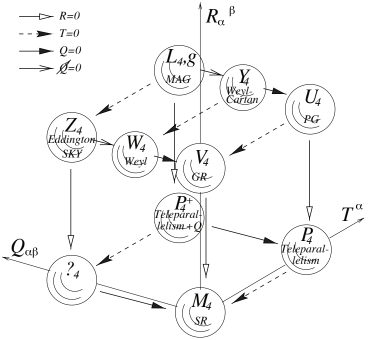

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- Make EM independent of spacetime curvature, torsion, etc. Roughly, only need continuous, smooth spacetime.
- This approach: Kottler (1922), Cartan ('23), van Dantzig ('34). Related: Einstein, Mie, Sommerfeld.

Figure: Hehl and Obukhov (Birkhäuser, 2003).

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Figure: Charlie Chaplin, "The Great Dictator", 1940.

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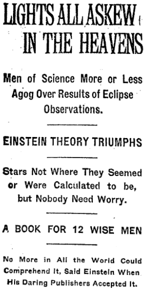
- EM needs $\sim$ continuity and smoothness only. Not distance, curvature, etc. If spacetime was a globe, we would not care about distances, or the curvature.
- We would only demand a continuous, smooth surface (smooth transition between the pages of an atlas).

Figure: Charlie Chaplin, “The Great Dictator”, 1940.

Towards the experiment side of things.



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Men of Science More or Less Agog Over Results of Eclipse Observations.

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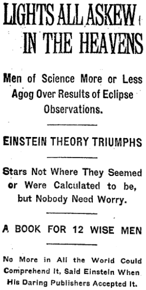
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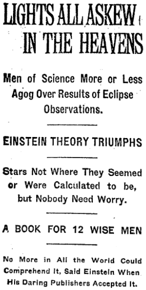
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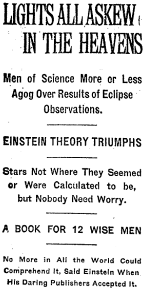
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Type of the detector	Mass (kg)	Resolution (keV)	Backgr. (keV kg yr)$^{-1}$	Raw data	Limits τ (yr) (c.l.) mode: $e^- \to \nu_e + \gamma$	Ref., Year
NaI	5	–	–	–	$> 1.0 \times 10^{19}$ (68%)	[4], 1959
NaI	1.4	44 (–)	~ 21020	No	$> 4.0 \times 10^{22}$ (68%)	[5], 1965
NaI	6	43 (–)	$\sim 3 \times 10^5$	Yes	$> 3.5 \times 10^{23}$ (68%)	[6], 1979
Ge (Li)	0.69	~ 1.5	1500	Yes	$> 3 \times 10^{23}$ (68%)	[17], 1983
HPGe	0.71	1.9 (5.13)	240	Yes	$> 1.5 \times 10^{25}$ (68%)	[7], 1986
HPGe	3.1	2.5 (7.6)	25.8	Yes	$> 2.4 \times 10^{25}$ (68%)	[8], 1993
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LXe (DAMA)	6.5	78 (80)	0.04	Yes	$> 3.4 \times 10^{26}$ (68%)	[24], 2000
CTF ($C_{16}H_{18}$) (Borexino)	4170	72 (–)	0.06	No	$> 4.6 \times 10^{26}$ (90%)	[10], 2002
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- Compare with age of universe $\sim 10^{10}$ years. Conserved?

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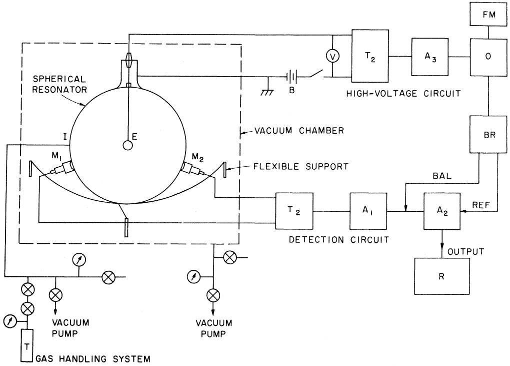
- Dylla and King (PRA, 1972). Record sound in electrically-driven gas-filled chamber. Get force at electrical drive, thus $|(q_e - q_p)/q_e| \leq 2 \times 10^{-19}$.



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- Measurements by Marion et al. (PRL, 2003) show that potentially $|\dot{q}_e/q_e| \leq 3.6 \times 10^{-16}(\text{years})^{-1}$.

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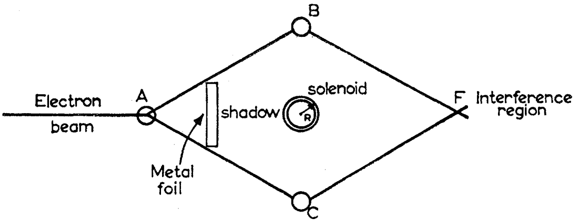

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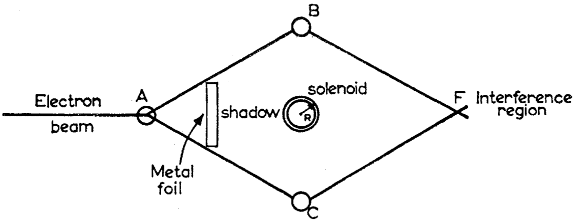
- "Step" in zero B-signal can be used to detect magnetic monopoles. (Proposed, Lämmerzahl et al., PRD 2005).



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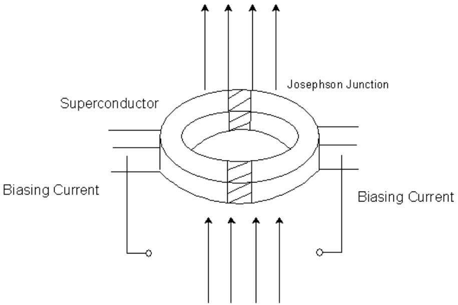

Fig.: Barron/Maguire-Boyle, "Nanothechnology for the Oil and Gas Industry" (Online Collection, 2011).

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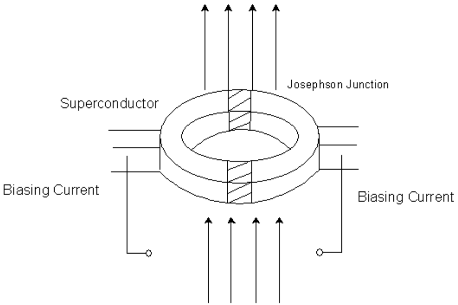

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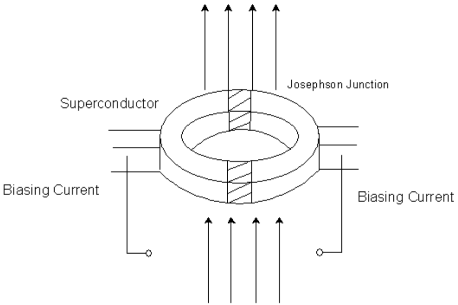

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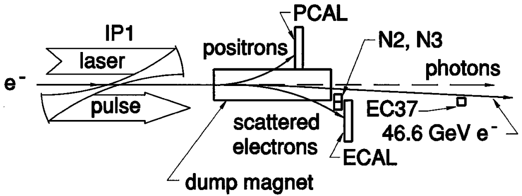
- QED: photons scatter photons. Self-effect, nonlinear.
- Self-effect seen in high energy γ (NOT macroscopic).
- Left: Burke et al. (PRL, 1997), increased positron production due to multiphoton light-by-light scattering.
- Right: Akhmadaliev (PRC, 1998), γ turned into virtual $e^- e^+$ pair, and scattered off nucleus to get new γ.



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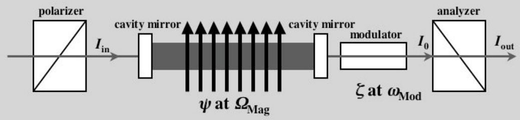
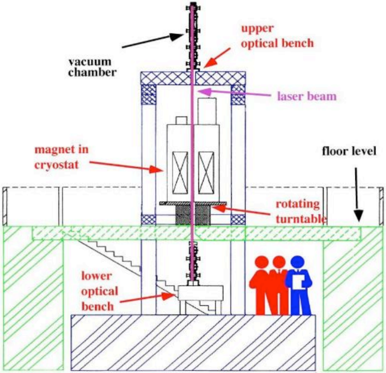
In recent years, growing number of experiments...

PVLAS Collaboration, (arXiv:0805.3036v1).

- Measures birefringence $\psi = \pi(n_{||} - n_{\perp})L/\lambda$.





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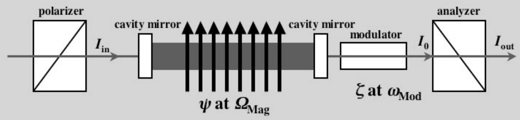
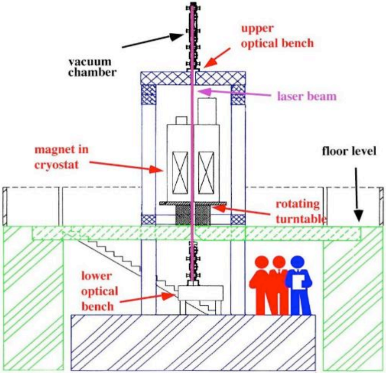
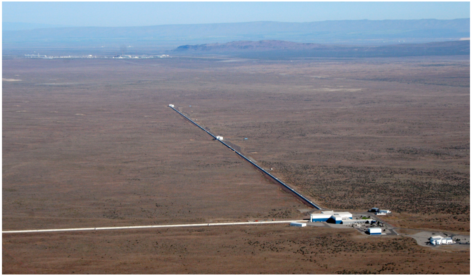
- Measures birefringence $\psi = \pi(n_{\parallel} - n_{\perp})L/\lambda$.
- Heisenberg-Euler: sensitivity not enough by factor 4800.





Detection by Michelson interferometry (TO DO).

- Large coil installed on one arm, modifies speed of light.
- Test will work for Heisenberg-Euler and Born-Infeld.
- Döbrich/Gies (EPL, 2009): "For our quantitative estimates, we have concentrated on the advanced LIGO, as its sensitivity goal matches with currently available field strengths". (Figure: taken from LIGO website.)



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- Hehl/Obukhov (Birkhäuser, 2003), Delphenich (Annalen der Physik, 2007), Lindell (Metamaterials, 2008), Obukhov/Favaro/Lindell/Bergamin (in progress).

Requirements for a general material*.

The requirements constraining a general vacuum can be interpreted as requirements on a general laboratory material. Actually, talking of materials. . .

General material to allow TE/TM decomposition.

- Lindell/Bergamin/Favaro (IEEE, submitted).
- Lindell/Bergamin/Favaro (PIER, 2011).

Other metamaterials stuff. . .

Conclusions.

- Maxwell's equations only require spacetime $\sim$ continuous and smooth. Nothing more.
- Eliminating unnecessary assumptions puts the focus on a $\sim$ minimal set of experiments.
- Charge conservation $\Rightarrow$ Inhomogeneous Maxwell's Eqs.
- No mag. monopoles $\Rightarrow$ Homogeneous Maxwell's Eqs.
- Vacuum response assumed late: after Maxwell's Eqs.
- Maybe nonlinear? Remember, QED says so...
- Maxwell's theory is still fundamental science.

Thank-you!