Energy extraction from the Zero-Point Field using Casimir cavities in the realm of Stochastic Electrodynamics

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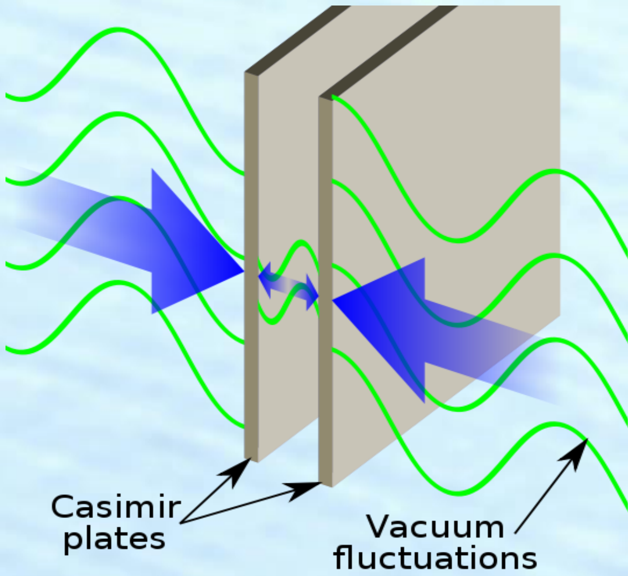
Introduction

1) Zero-Point Energy (ZPE)

- Quantum Mechanics (QM) predicts:
  - Even at zero kelvin **there is energy** filling the vacuum
  - Zero Point Field fluctuations (ZPF) – imposed by the Uncertainty Principle

2) Influence of the ZPF

- Cannot be directly observed (“virtual”)
- But its effects has been experimentally detected:
  - The Lamb Shift
  - The spontaneous emission
  - The Casimir Force
- **Casimir force** between to plane reflectors:
  - Originated by the electromagnetic differential pressure
  - Theoretically it allows **to extract energy from the ZPF**, without violating any thermodynamic law
  - Unfortunately, only works once, not in a continuous cycle



Introduction

3) ZPF in our study

- Just the **electromagnetic** part of the ZPF
- We prefer to treat ZPF within the realm of **classic mechanics**

the matter-ZPF interaction **equal to** the rest matter-radiation interactions

in QM

ZPF = "virtual" photons

≠

"real" photons

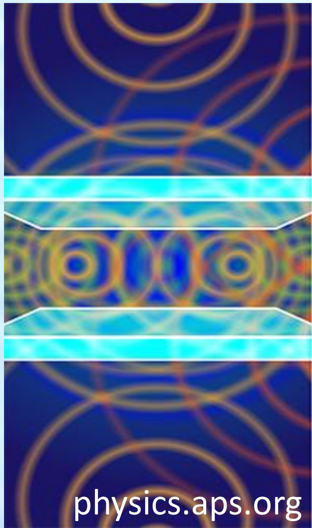
Classic mechanics

ZPF = real electromagnetic waves

no distinctions

4) Extracting energy from ZPF (continuous cycle)

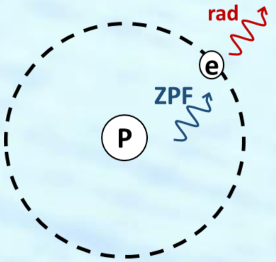
1. For make energy flows → a lower energy state region is required
2. Such as the inside a **Casimir cavity**
3. The energy from outside must be stored with some **mechanism**
4. Inside the cavity this device can **release the energy** in excess



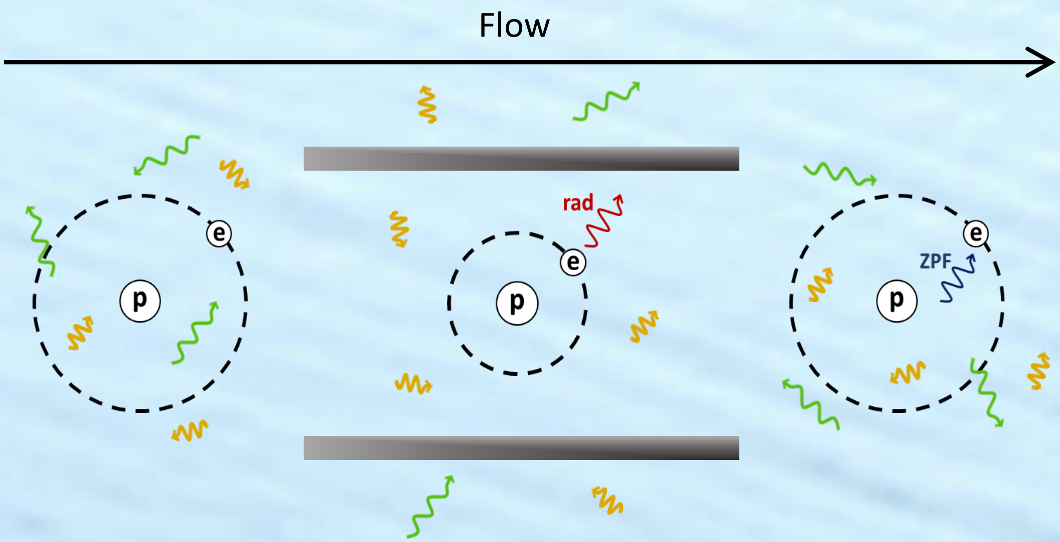
Introduction

5) Stochastic Electrodynamics (SED)

- Relativistic classic mechanics + ZPF
- Orbiting electrons → accelerated charges
  → radiates (spinning down towards the nucleus)
- But they also absorb energy form the ZPF
- Equilibrium between radiated and absorbed power
  → **atomic stability**
- Atoms could be that **"mechanism"**



The averaged radius is predetermined by the ZPF spectrum



1. Inside a Casimir cavity → the ZPF is modified
2. Atoms can undergo a shift in their states
3. Releasing Larmor radiation in that process
4. **Just flow ground state atoms through Casimir cavities**

Introduction

6) Goals

- Simulate the interaction between atoms and the ZPF
- Detect the possible shifts in the atomic states induced by Casimir Cavities
- **Proof of concept**: method to extract useful power from ZPF

7) Motivation

- ZPF → inexhaustible energy source: integrating up to the Plank frequency $(10^{43}\ Hz)$ **VACUUM DENSITY →** $\mathbf{10^{113}}\ \boldsymbol{J/m^3}$
- **Green** and available **everywhere** → ensuring the sustainability of future generations
- Study of the **SED**: a fundamental theory that still remains little explored (SED could explain the genesis of Quantum Mechanics)

Stochastic Electrodynamics (SED)

SED = Newton's equation of motion (relativistic) + wave equations of Maxwell + Random Electromagnetic background

$$\rho(\omega) = \boxed{\frac{\hbar\omega^3}{2\pi^2 c^3}}$$

$\frac{1}{2}\hbar\omega$ per mode

The only possible spectrum
(Lorentz invariant)

$\hbar$ comes from experimental data
Nothing to do with QM

SED was able to explain:

- In SED the quantization arises naturally
- Casimir and van der Waals forces
- Plank blackbody radiation
- Unruh effect
- Uncertainty principle

Some more controversial:

- Inertia
- Gravitation

But still lack many systems, such as the atom inside a Casimir cavity…

Classically: matter is continually **radiating** (radiation reaction)

Radiation from distant matter = **ZPF**

ZPF compensates energy losses → stability

SED – Hydrogen atom (H)

- Newton's second law of motion for $\boldsymbol{e}^{-}$ in $\boldsymbol{H}$ (non-relativistic)

Coulomb

Radiation reaction

ZPF force from E and B

$$m\frac{d^2\boldsymbol{r}}{dt^2} = -\frac{e^2\boldsymbol{r}}{4\pi\varepsilon_0|\boldsymbol{r}|^3} + \frac{2e^2}{3c^3}\frac{1}{4\pi\varepsilon_0}\frac{d^3\boldsymbol{r}}{dt^3} - e\left\{\boldsymbol{E}[\boldsymbol{r}(t),t] + \frac{d\boldsymbol{r}}{dt}\times\boldsymbol{B}[\boldsymbol{r}(t),t]\right\}$$

- Expansion of plane waves (Maxwell's equations in a bounded space)

$$\boldsymbol{E}_{ZPF}(\boldsymbol{r},t) = \frac{1}{\sqrt{(L_xL_yL_z)}}\sum_{n_x,n_y,n_z=-\infty}^{\infty}\sum_{\lambda=1,2}\hat{\boldsymbol{\varepsilon}}_{\boldsymbol{k_n},\lambda}\left[A_{\boldsymbol{k_n},\lambda}\cos(\boldsymbol{k_n}\cdot\boldsymbol{r}-\omega_{\boldsymbol{n}}t) + B_{\boldsymbol{k_n},\lambda}\sin(\boldsymbol{k_n}\cdot\boldsymbol{r}-\omega_{\boldsymbol{n}}t)\right]$$

integers

Cavity dimensions (big for free space)

Gauss distribution

Mean = 0

Variance = $\frac{\hbar\omega_{\boldsymbol{n}}}{2\varepsilon_0}$

$$\omega_{\boldsymbol{n}} = c|\boldsymbol{k_n}|$$

$$\boldsymbol{B}_{ZPF}(\boldsymbol{r},t) \Rightarrow \frac{1}{c}\hat{\boldsymbol{k}}_{\boldsymbol{n}}\times\hat{\boldsymbol{\varepsilon}}_{\boldsymbol{k_n},\lambda}$$

$$\boldsymbol{k_n} = 2\pi\left(\frac{n_x}{L_x}\hat{\boldsymbol{x}} + \frac{n_y}{L_y}\hat{\boldsymbol{y}} + \frac{n_z}{L_z}\hat{\boldsymbol{z}}\right)$$

SED – H in the free space - simulations

The atom was never fully described by SED

Difficulties in the analytical solving, owing to the **non-linear** Coulomb potential

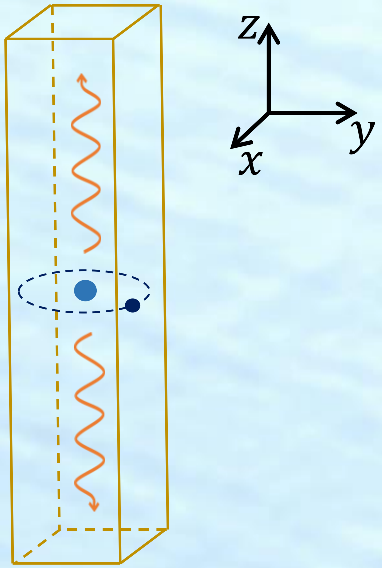
→ solution: **numerical integration**

Approximations to speed up the numerical integration

originally proposed by Cole and Zou (2003):

Long enough to consider it in free space

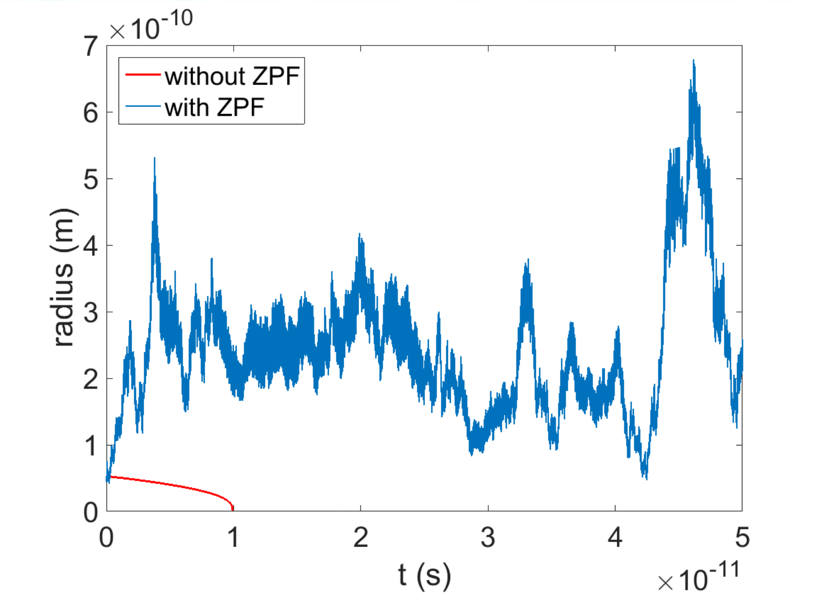
- To force a 2D orbit in xy:
  1. Narrow cavity → L_x = L_y= $3.74\ nm$ and L_y= $\mathbf{4.1\ mm}$
  2. No $\overrightarrow{B}$, and $\overrightarrow{E}$ waves in only one direction (z)
- At each iteration: just the waves in resonance with r
  → within a frequency window $r \pm 0.03r$
- No waves for r below $r_{min} = 1 \times 10^{-11}$

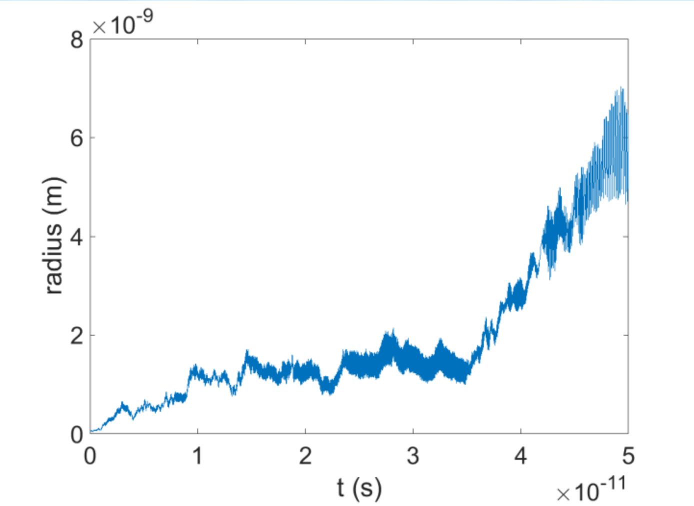


SED – H in the free space - simulations

- In order to get a better statistics , 261 simulations were carried out
  (Cole and Zou (2013) made 11 simulations)
- Only 64 reached the final time = 5×10^{-11} s
  (longer than Cole and Zou)

Comparing the classic decay with the SED's result → the ZPF seems to avoid da atomic colapse

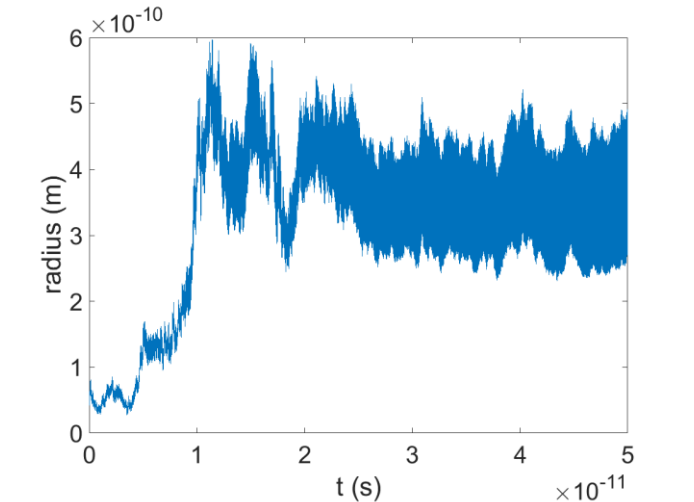




Some runs were not so good:

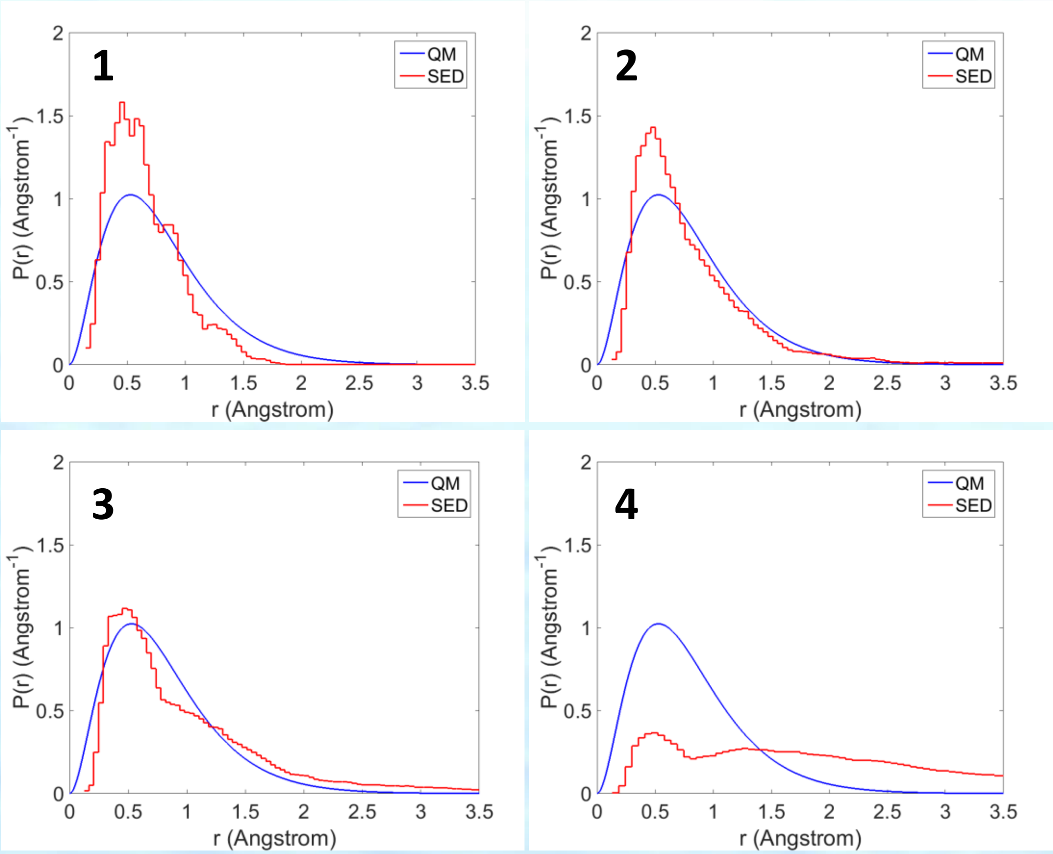
Extremelly elliptic orbits → randomness decreased

← Continuously rising orbits (spontaneous ionization)



SED – H in the free space - simulations

- Histograms of all simulations summed (as Cole and Zou done)
- It's included in each histogram only the radius up to a certain **time limit**
- This time limit increases **from 1 to 4**
- If there is no trends over time, this is just the same as increasing the statistics



The radius distribution from SED converges to the QM's prediction (blue curve)

Longer time limit → greater statistics, but...

Diverges from QM

Is the averaged radius time dependent?

SED – H in the free space - simulations

- Average radius as function of time (blue line) → there is in fact a **trend** over time towards spontaneous ionization – are the electron absorbing excess of power from the ZPF?

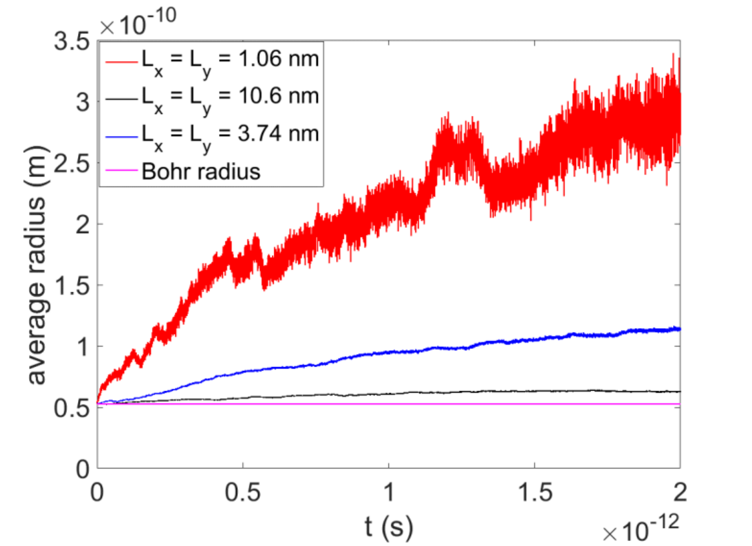
➢ **Possible causes:**

1) The computational model or even the SED are wrong

2) The utilization of minimum radius → $r_{min} = 0.1$ Å

3) The use of only the waves in resonance with the orbit (frequency window)

4) The use of only $\vec{E}$ waves in just one direction imposed by the cavity dimensions → if L_x and L_y are changed, the model should still describe the free space, however owing to the normalization constant $\left(1/\sqrt{(L_x L_y L_z)}\right)$ the amplitude of the waves will be changed too



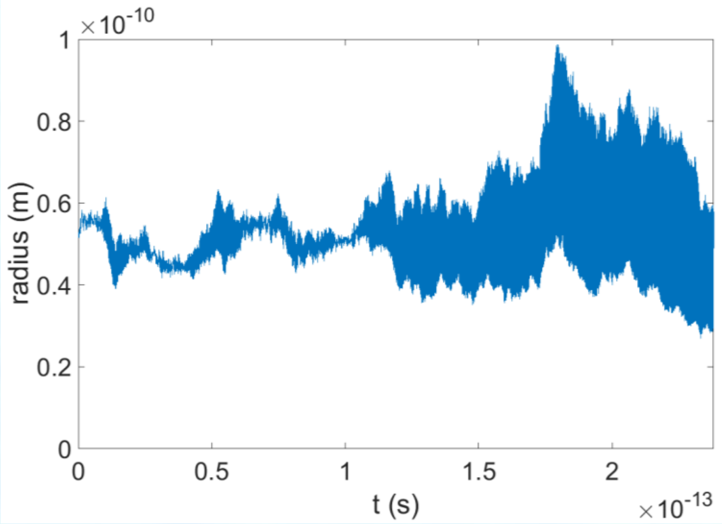
Simulations for two diferent L_x and L_y → as we suspected this parameters have a strong influence on the results, **so it could be the problem**

SED – H in the free space - simulations

1) In the case where L_x and L_y were decreased, the r_{min} was consequently decreased for 0.43×10^{-11} $\rightarrow$ There were even more simulations reaching the r_{min} → **most likely the lower radius limit is not the problem**

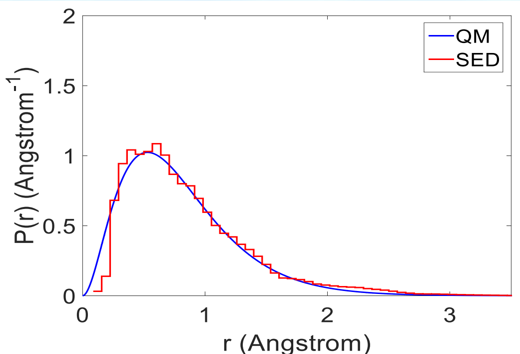
2) We performed an additional simulation where all the waves **except** the ones in resonance were included

➢ This waves have also a great influence in the radius of the orbit → **the frequency window could be the problem**



Conclusion: The origin of the problem could be a combination of these discrepancies

Interesting note: owing to a bug in the code we generated waves just in x and traveling in only one orientation, where the **best match** with QM was achieved

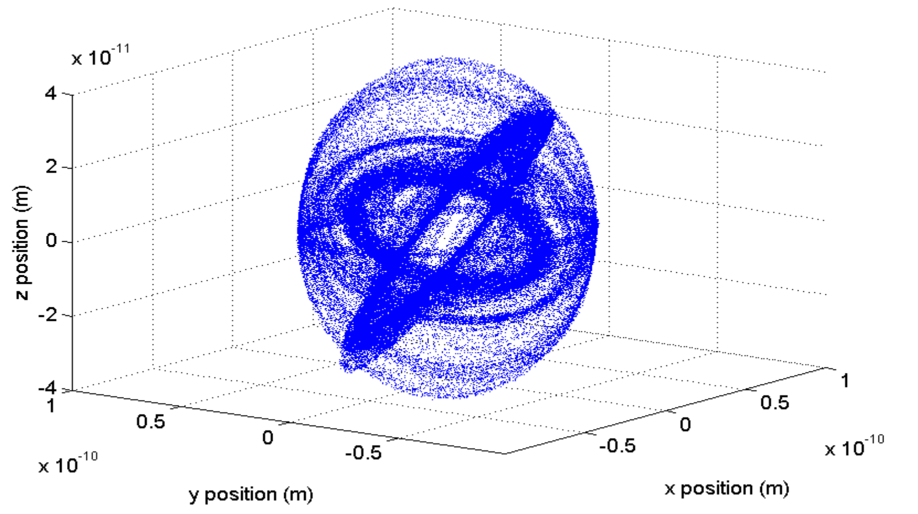


SED – H inside a Casimir cavity

➢ To solve the discrepancies found in the Cole and Zou's model:

1D ZPF → 3D ZPF

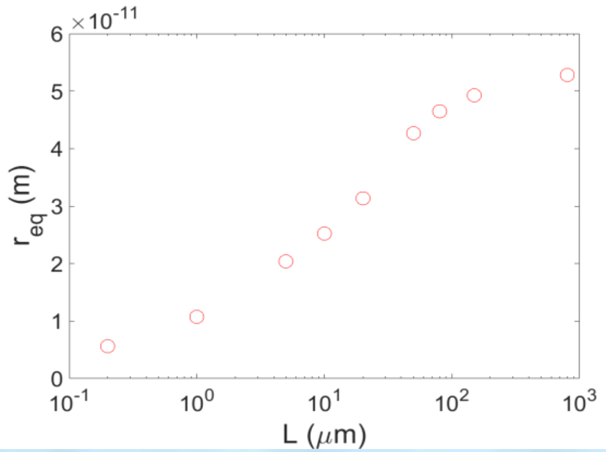
- Much more computationally heavy
- It allows to simulate the Hydrogen in 3D



↑ 3D Hydrogen inside a cavity

It was not possible yet to validate this model for the free space with our actual computational resources

We computed the equilibrium radius (r_{eq}) of the orbit for cavity case using the 3D ZPF :



← r_{eq} decreases as the edge (L) of the cubic cavity decreases

Unfortunately these results are **not reliable** due to the many considerations we have done:

- We used the analytical equation of the **absorbed power** according to the Harmonic Oscillator approximation
- We used the **radiated power** characteristic of the free space

Methods to extract energy from the vacuum

Many questions and hypotheses…

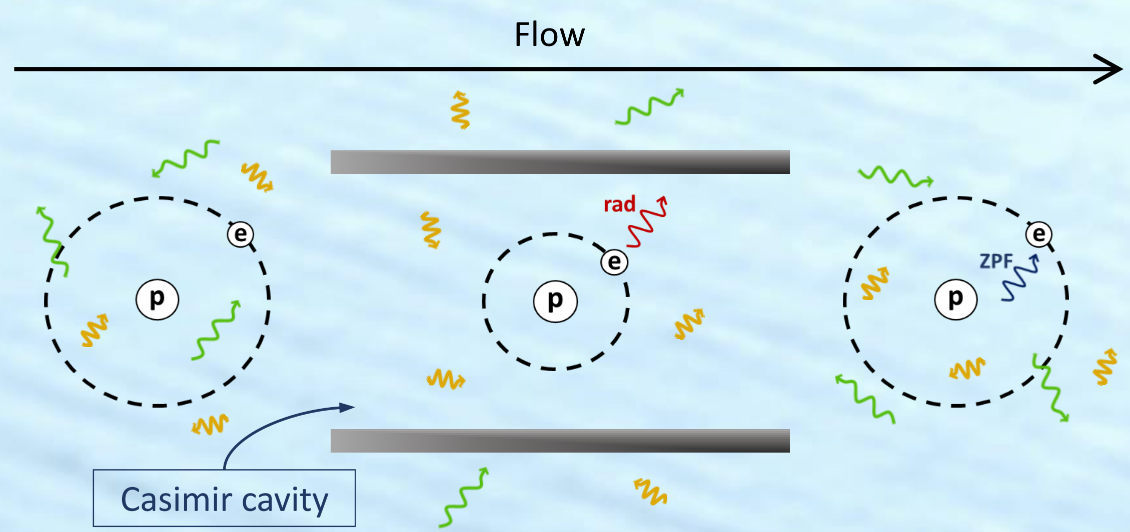
?

If there are shifts, how will they occur?

1. Progressively in a **spiral-like** decay orbit, emitting Larmor radiation at the electron spinning frequency
2. In a **transition-like** process, most likely with a characteristic half-life time and emitting radiation whose frequency is related to the shift

Ground state reduction method (without excitation):

- Ground state atoms flowing through Casimir cavities
- May be necessary supress the ZPF's modes in resonance with the valence orbits



Methods to extract energy from the vacuum

Ground state reduction method (state of the art)

- Moddel and Dmitriyeva's experimental data was inconclusive (IR-region)
- Puthoff was not able to detect the H_2 molecular ground state shift

Possible causes…

1) The shifts were outside the studied energy ranges
   → study other energy ranges (visible and UV)
2) There is no shift in the ground state
   → try excited states
3) The shift is hard to detect
   → try excited states
4) A transition between states is required to the shifts take place → search for an energy gain in transitions
5) There is no shift at all ☹

Owning to the *fluctuation-dissipation theorem* no major shift in the **H**armonic **O**scillator's equilibrium state is expected, only small radiative corrections

However **HO** $\neq$ **atoms**

1. Waves can be themselves supressed inside the cavity
2. Their energy can be hard to distinguish from thermal noise

In excited states a higher shift is expected since the electrons' orbits have lower frequencies

Transition + shift have a smaller wavelength than the shift alone

Methods to extract energy from the vacuum

With excitation:

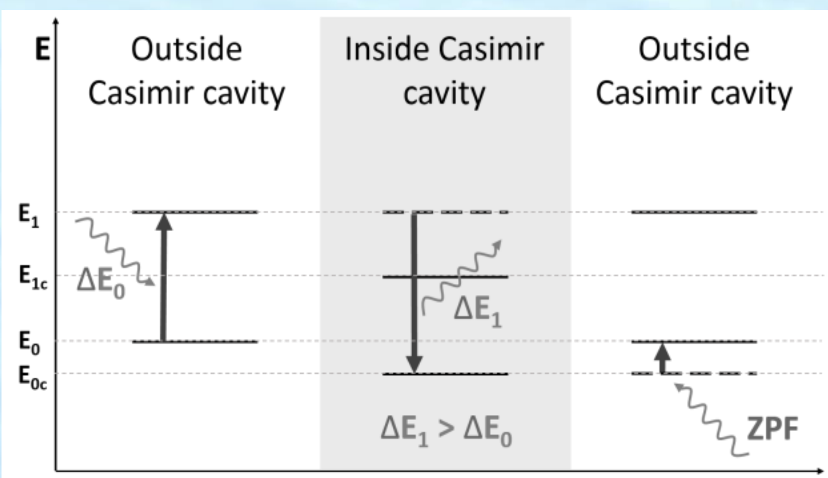
- ➢Radiation emitted directly from the shift → Flowing the excited atoms through the cavities (we did not test this hypothesis)
- ➢Energy gains in atomic transitions

If the shift only happens through a transition…

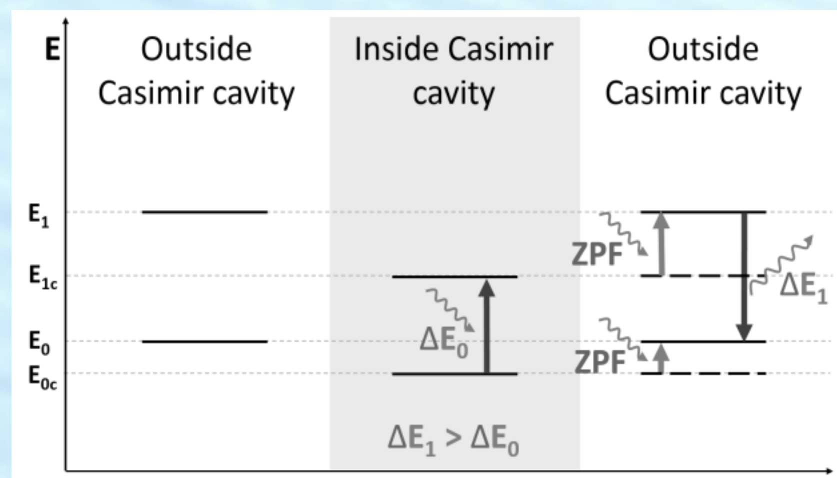
EI-method: gain = ground-state shift

If there is no need for a transition and most likely the shift is immediate as the atom enters…

EO-method: gain = excited-state shift (higher)



Excite-Inside-Method (EI)



Excite-Outside-Method (EO)

Experimental setup

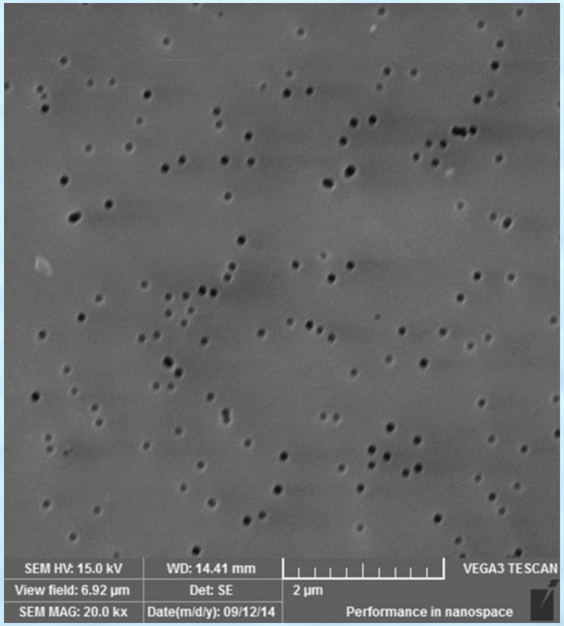
- **Casimir cavity**

Metals become bad reflectors above their plasma frequency

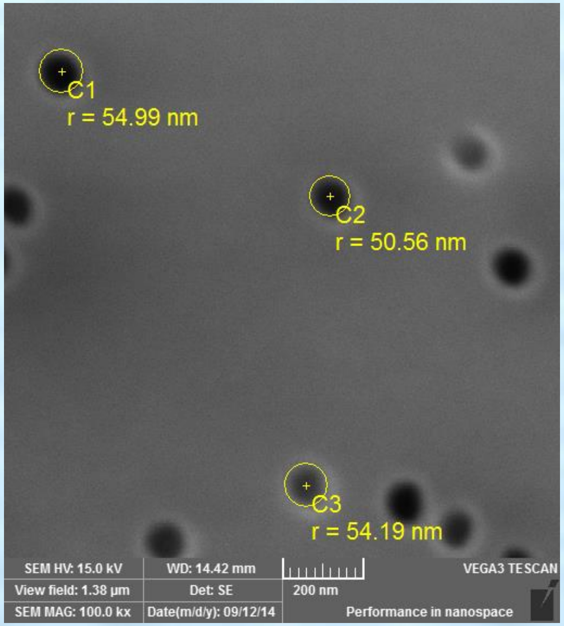
→ **Aluminium** is the better choice since its reflectance is still high at the VUV region (~90% @ 200 nm)

SEM photos (d=100 nm)

↓ 20 000 ×



↓ 100 000 ×



We used: Nuclepore Track-Etched Polycarbonate **nano-porous membranes** coated with **Al**

Pores diameter (d): 50 and 100 nm

Thickness: 7 - 20 μm

Differential pressure: 0.69 bar

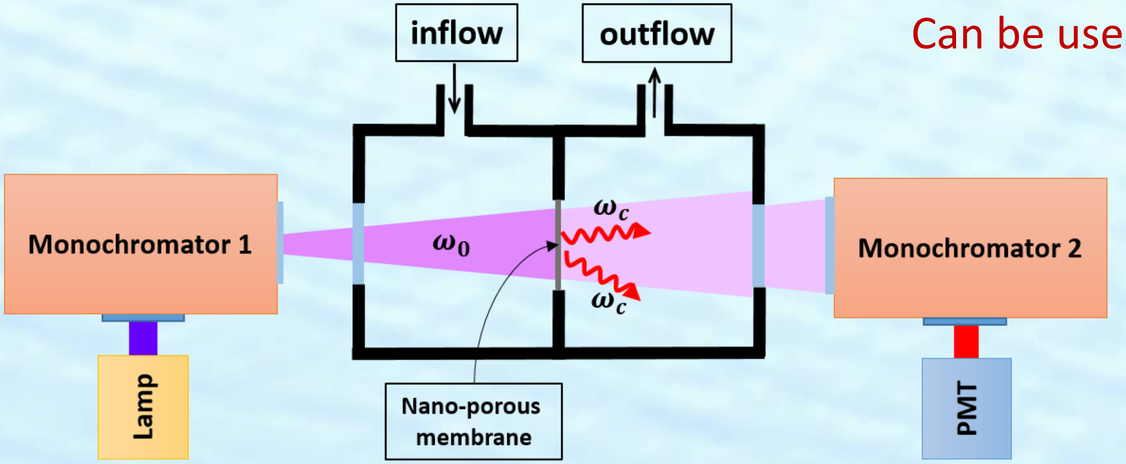
Pore density: 10^5 - 6×10^8 cm^{-2}

Experimental setup

- Designed to detect energy gains in atomic transitions

The **MC 1** excites the atoms with $\boldsymbol{\omega_0}$ and the **MC 2** records the emitted radiation, when a $\boldsymbol{\omega_c > \omega_0}$ is detected, there was an **energy gain**

Can be used with EI-method or EO-method



PMT: 160 - 650 nm, also operable down to ~ 115 nm (less sensitive)

MC1 and MC2: ~30 - 550 nm

Lamp: deuterium, continuous spectrum 115 - 370 nm

Chamber: stainless steel vacuum system, pumped with two turbo-molecular

- Turning off the **MC1**, we can also detect the emitted radiation from ground state flowing atoms (Ground state reduction method)

Gas: Xenon, because is the heavier noble gas and have the resonance transition of lower energy ($^3P_1$ $\lambda \approx 147.1\ nm$)

Data acquisition: a Multi-Channel Analyser

Experimental setup

➤ Our instrumentation

Membrane

Results and Discussion

With excitation (pores = 100 nm)**:**

1. **Exciting:** in the **Xe resonance transition** ($\lambda = 147.1\ nm$)
   → testing the shift in the ground state (Excite-Outside-Method)

   Scanning: from 107 – 147 nm

No radiation detected, neither for λ < 147.1, nor for excited λ = 147.1 nm itself

2. **Exciting:** in three different wavelengths ($\lambda = 250.2\ nm$, $210.2\ nm$, $165.2\ nm$) **higher** than the Xe resonance transition
   → testing the shift in the excited state (Excite-Inside-Method)

   Scanning: from each emitted $\lambda + 20\ nm$, to 130 nm

No radiation detected for λ = 147.1 nm, and from all excited λ, only 250.2 nm was detected

Problems found:

PMT's bad sensibility below 160 nm

+

radiation losses in: MCs, Xe, solid angle and windows

Poor sensitivity

(evident in the non-detection of the excited λ)

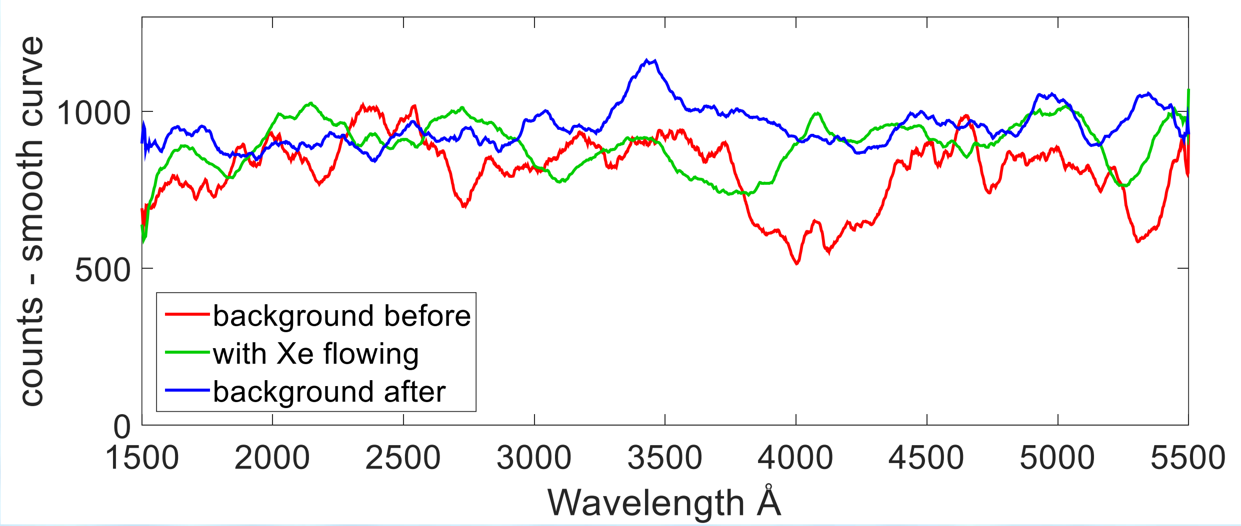
So, we did not consider these results conclusive

Results and Discussion

Without excitation – spectroscopy (pores = 100 nm)**:**

- With Xe flowing through the membrane, green line (differential pressure $\sim 0.4\ mbar$)
- Two background spectrums (red and blue lines), one being made before and other after the main experiment

No radiation detected



At this time the sensitivity was greater, even so, it was not optimal

Smooth curves adjusted to the experimental data to facilitate the visualization

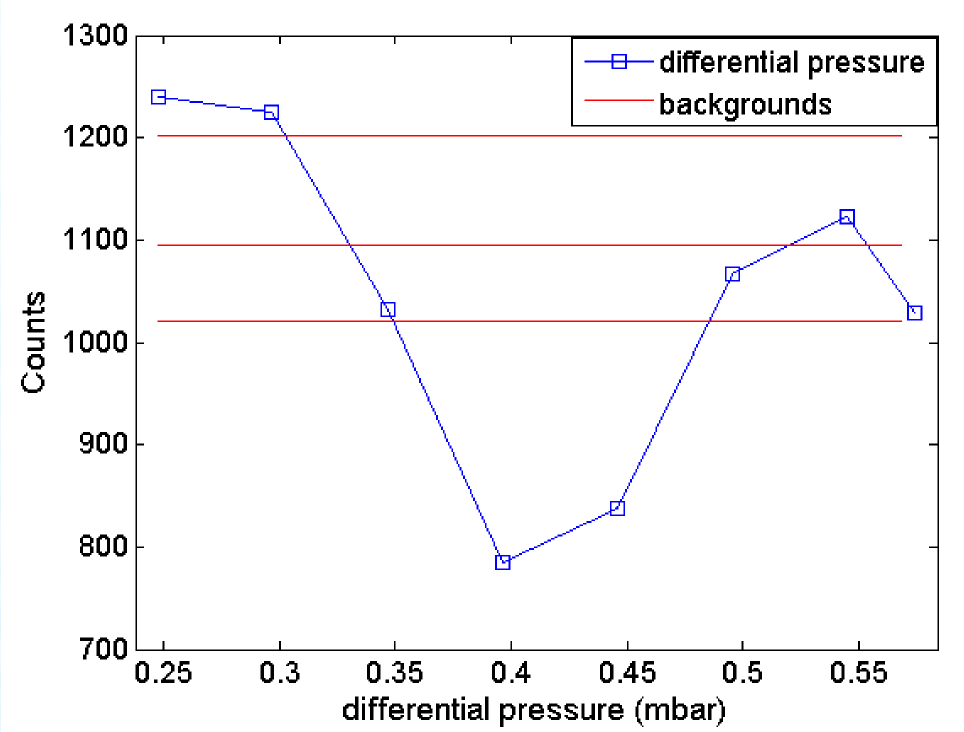
Results and Discussion

Without excitation – quantitative (pores = 50 nm)**:**

➢ **Without MCs**, with the PMT assembled some mm away from the membrane (at the gas entrance side)

Great sensitivity from 160 - 650 nm

- The flow increases with the differential pressure (with the exit side being always in vacuum)
- Comparing with 3 backgrounds
- **No radiation at all was detected**



↑ photo-counting as a function of the differential pressure

Conclusions

Computational research:

1) Cole and Zou's model **is not suitable** to describe the H in free space:

- For longer integration times the radius distribution diverges from the QM's prediction
- The averaged radius have a continuous trend to outer orbits
- The narrow cavity approximation (L_x, L_y - short and L_z - large) is not proper for the free space

Experimental research:

1) The tests using preliminary **excitation** were not conclusive since our instrumentation showed a poor sensitivity within the studied energy ranges

2) If **ground state** Xe atoms radiates as they enter into Casimir cavities
   → the radiation's energy is **not** in the ranges:

   - 2.3 – 7.8 eV for pores =100 nm, low sensitivity
   - 1.9 – 7.8 eV for pores = 50 nm, high sensitivity

Future research

Computational research:

- Validate the 3D-model for the **free-space** and then use it for **cavities** (using the modified radiation reaction force)
- Simulate the excited states and atomic transitions

Experimental research:

- To increase the sensitivity:
  - Using other atoms whose transitions have lower energies
  - Improve all the optical system: lenses, geometry, windows, PMT…
- Use nano-porous membranes integrally made of metal
- Explore the shifts in the ionization and molecular dissociation energies

Future research – new concepts

- The orbit is **strongly** affected by ZPF's modes **outside the resonance**
  → most likely, these modes also perform **positive work** on the electron

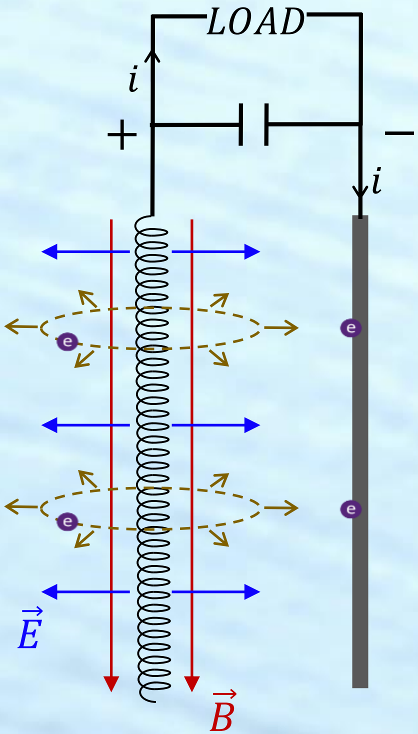
Using proper cavities, radiation, magnetic/electric fields or even a specific electromechanical device, a motion with a **fixed frequency** could be achieved
→ an **excess of radiation** at such frequency would be detected since part of the absorbed energy comes from other frequencies

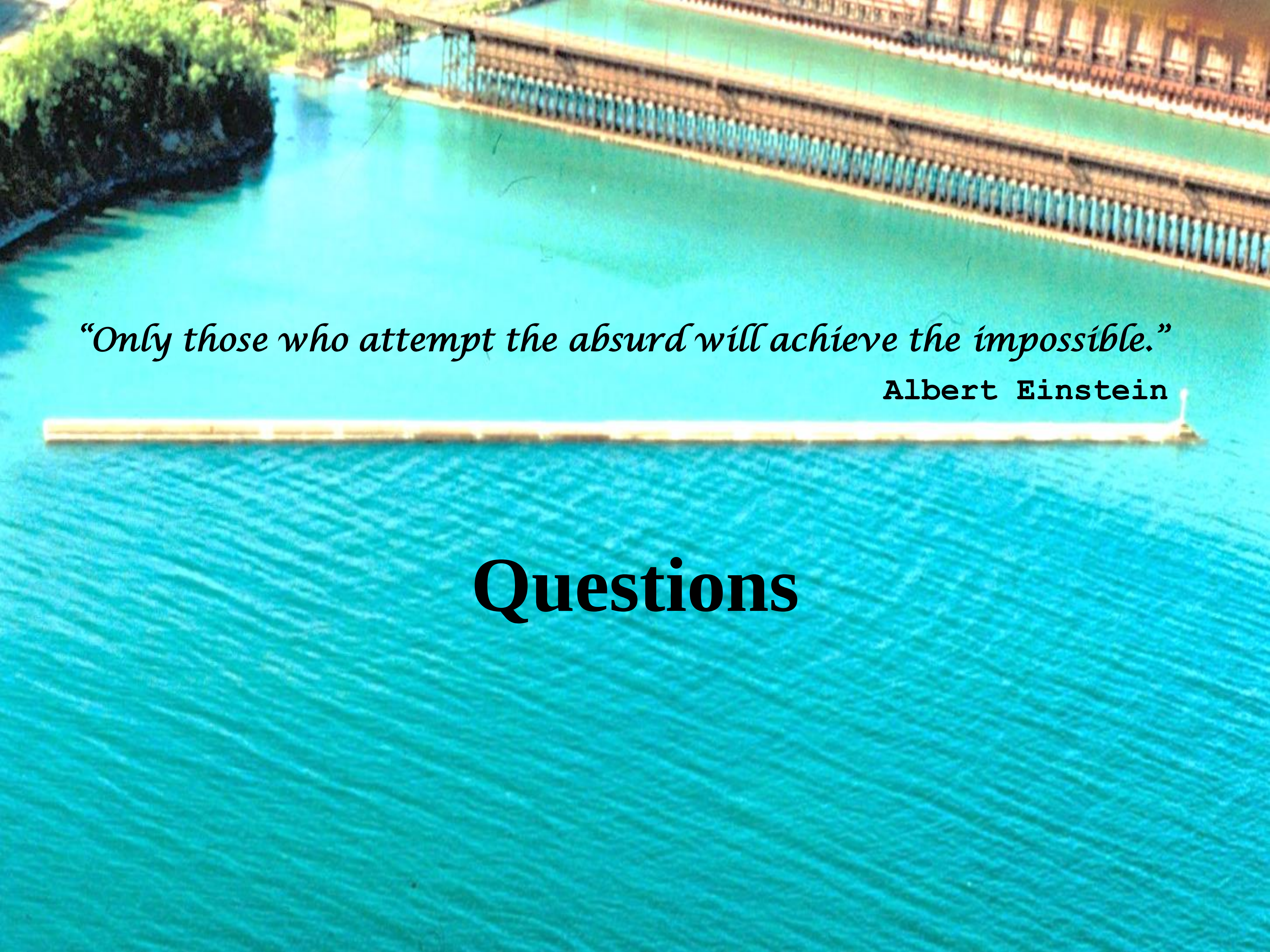
- We showed that the ZPF can increase the averaged potential and kinetic energy of the orbiting electrons

We can use this principle to make the electrons move against the electric potential in a proper device

Just an idea:

1. The electrons leave the positive pole by thermionic emission
2. A magnetic field make them to curve and get in orbit around the positive pole
3. Due to the ZPF, the average orbit radius increases resulting in a motion of the electrons from the positive pole to the negative one





"Only those who attempt the absurd will achieve the impossible."

Albert Einstein

Questions

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