Basic research & theoretical physics in Molde

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Molde University College

Per Kristian Rekdal, 28th September 2012
Presentation of myself
Fundamental research
Quantum optics
Quantum computers
Atom chip
Lifetime (decoherence)
Collaborators
Summary
Presentation

Name: Per Kristian Rekdal

Age: 39

Education:

# published papers: 15

h-index: 6
Fundamental research: what is it?
Fundamental research:

- research carried out to increase understanding of fundamental principles
- not intended to yield immediate commercial benefits
- however, in the long term it is the basis for many commercial products and applied research
I have seen it all!
\[ \mathcal{L} = i \bar{\psi} \gamma^\mu \partial_\mu \psi - e \bar{\psi} \gamma_\mu (A^\mu + B^\mu) \psi - m \bar{\psi} \psi - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} \]

\[ \partial_\mu \left( \frac{\partial \mathcal{L}}{\partial (\partial_\mu \psi)} \right) - \frac{\partial \mathcal{L}}{\partial \psi} = 0 \]
Higgs particle
Se det første bildet som noensinne ble publisert på nettet.
INTERNET EN FLOPP!

Dataekspertene og såkalte fremtidsforskere spør først i gang at Internett vil bli dominerende i vårt dagligliv i de nærmeste åren, førde vi vil bli nødt til å ta den i bruk via vår hjemme PC. Tilhøvervisning av slike gale trend-baserte påstander er nå nødvendige, og her er en mothypotese: Internett er en flopp. Det vil si et motregre, som kommer til å druknet ut om et par år.

Det er tre grunner til dette: 1) ingen av aktører på nettet vil ikke tørke på å legge seg der med sine tilbud, 2) privat bruk av nettet vil være marginal, og 3) mengden av informasjon på nettet vil bli så enorm at det vil skape frustrerende store søkeproblemer, og dermed friluft av brukere. Hva gjelder punkt 2 så tror jeg at vi snart vil se hver enkelt hemanalysen fra Internett, når disse oppdager at de har hatt seg selv, redde for å være moderne eller være tilstede der ville de andre.

I 2000 var det en utgangspunkt i hva flere mediegarner sier. De uttalte at Internett innen året 2000 vil være et like naturlig del av dagliglivet som telefonen. Da er det alvorlig mulig at jeg er i feil.

Motregre, Internett er et motregre som kommer til å druknet ut om et par år, mener Leif Ostwald.

Det er bruken av PC som teller, ikke besittelsen. Grunnen til dette er simpelthen at mennesket er et sosialt evne, og etter en stall kommer til å bli let av å kommunisere med en maskin i fritiden. PC i hjemmet kommer i all hovedsak til å benyttes til jobb- og fritidsrelaterte oppgaver, samt til spil og underholdning. Og selv vekst om disse positive anvendelsene blir små, også på lang sikt.


Så må arbeidet kommer derfor heller aldri til å bli særlig utpekt, men fortsette ved å drive virksomheten, ikke bare mestre det.


Disse tingene vil ikke kunne erstatte av PC-opplevelser, og slik vil det helhvisvis fortsette å være, fort slik er den menneskelige natt. Kort oppsummer: de sosiale basis-behov hos oss står i direkte motstrid til bruk av datamaskiner i hjemmet, og vil naturligvis seire i det lange jøp. Og når det gjelder bruk av Internett før det kan all verdens informasjon, så tror jeg at dette vil druknet ut av seg selv. Vi er allerede overført med informasjon, og før dessuten den vi trenger byrde med, radiotv.

Idag er det kun én prosent av befolkningen som bruker Internett hjemme, og særlig flere tør.

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Basic research & theoretical physics in Molde
Per Kristian Rekdals field of research: Quantum Optics
Quantum Optics: (definition)

- light and its interactions with matter
- described by: quantum mechanics
Atom & Photon: ⇒ Quantum Mechanics

Atom:

Photon:

Quantum Mechanics
Two quantum properties:

1) superposition, adding states $\Rightarrow$ interference
2) entanglement, “coupling” of quantum systems
1) Superposition

P = probability for coincidence click

(beam splitter)

SUPERPOSITION

(INTERFERENCE)
2) Entanglement

Electrons:

Pluto

ENTANGLEMENT

UP

Earth

DOWN

( coupling )

Video: 04 Entanglement, Dr. Quantum, (1 min. 3 sec.)
Einstein:

“Spooky action at a distance”
Many applications!
Video: 01 CNN - QC, (2 min. 25 sec.)
Physics of computing

Babbage’s computer

In 2017 single-electron gates

Silicon chips

1 meter

0.000001 m

atoms

0.0000000001 m
Moore: The number of transistors on a chip doubles every \sim two years
Bit vs Qubit

**BIT** (classical)

0 OR 1

**QUBIT** (quantum mechanical)

\[ |\text{qubit}\rangle = \frac{1}{\sqrt{2}} \left( |0\rangle + |1\rangle \right) \]

Video: 02 Quantum Computers, (2 min.)
1) Superposition

a) Classical computer: \((n = 3 \text{ bits register, i.e. } 2^n = 8 \text{ alt.})\)

\[000, 001, 010, 011, 100, 101, 110, 111\]

b) Quantum computer:

\[|\psi\rangle_{in} = c_1 |000\rangle + c_2 |001\rangle + c_3 |010\rangle + c_4 |011\rangle + c_5 |100\rangle + c_6 |101\rangle + c_7 |110\rangle + c_8 |111\rangle\]

where \(\sum_{i=1}^{8} |c_i|^2 = 1\)
Unitary operation: ( map )

\[ |\psi\rangle_{out} = \hat{U} |\psi\rangle_{in} \]

\[ = d_1 |000\rangle + d_2 |001\rangle + d_3 |010\rangle + d_4 |011\rangle \\
+ d_5 |100\rangle + d_6 |101\rangle + d_7 |110\rangle + d_8 |111\rangle \]

where \[ \sum_{i=1}^{8} |d_i|^2 = 1 \]
Example:

\[
\begin{align*}
|c_1|^2 &= \frac{1}{8} & c_1|000\rangle & & d_1|000\rangle & & |d_1|^2 = 0 \\
|c_2|^2 &= \frac{1}{8} & c_2|001\rangle & & d_2|001\rangle & & |d_2|^2 = 0 \\
|c_3|^2 &= \frac{1}{8} & c_3|010\rangle & & d_3|010\rangle & & |d_3|^2 = 1 \\
|c_4|^2 &= \frac{1}{8} & c_4|011\rangle & & d_4|011\rangle & & |d_4|^2 = 0 \\
|c_5|^2 &= \frac{1}{8} & c_5|100\rangle & & d_5|100\rangle & & |d_5|^2 = 0 \\
|c_6|^2 &= \frac{1}{8} & c_6|101\rangle & & d_6|101\rangle & & |d_6|^2 = 0 \\
|c_7|^2 &= \frac{1}{8} & c_7|110\rangle & & d_7|110\rangle & & |d_7|^2 = 0 \\
|c_8|^2 &= \frac{1}{8} & c_8|111\rangle & & d_8|111\rangle & & |d_8|^2 = 0 \\
\end{align*}
\]

\[
(\sum_{i=1}^{8} |c_i|^2 = 1)
\]

\[
(\sum_{i=1}^{8} |d_i|^2 = 1)
\]
Example:

\[
\begin{aligned}
|c_1|^2 &= \frac{1}{8} & |c_1\rangle &= |000\rangle \\
|c_2|^2 &= \frac{1}{8} & |c_2\rangle &= |001\rangle \\
|c_3|^2 &= \frac{1}{8} & |c_3\rangle &= |010\rangle \\
|c_4|^2 &= \frac{1}{8} & |c_4\rangle &= |011\rangle \\
|c_5|^2 &= \frac{1}{8} & |c_5\rangle &= |100\rangle \\
|c_6|^2 &= \frac{1}{8} & |c_6\rangle &= |101\rangle \\
|c_7|^2 &= \frac{1}{8} & |c_7\rangle &= |110\rangle \\
|c_8|^2 &= \frac{1}{8} & |c_8\rangle &= |111\rangle \\
\end{aligned}
\]

\[
(\sum_{i=1}^{8} |c_i|^2 = 1)
\]

\[
\begin{aligned}
d_1\langle 000| &= |d_1|^2 = 0 \\
d_2\langle 001| &= |d_2|^2 = 0 \\
d_3\langle 010| &= |d_3|^2 = 1 \\
d_4\langle 011| &= |d_4|^2 = 0 \\
d_5\langle 100| &= |d_5|^2 = 0 \\
d_6\langle 101| &= |d_6|^2 = 0 \\
d_7\langle 110| &= |d_7|^2 = 0 \\
d_8\langle 111| &= |d_8|^2 = 0 \\
\end{aligned}
\]

\[
(\sum_{i=1}^{8} |d_i|^2 = 1)
\]

constructive / destructive interference
1) Superposition (cont.)

Quantum computer: massive parallelism

Video: 03 QC, traveling sales man, (stop at 2 min.)
2) Entanglement

Electrons:

Pluto

ENTANGLEMENT

UP

DOWN

( coupling )

Earth

Video: 05 Entanglement, The Weirdness Of QM, (stop at 3 min. 27 sec.)
Applications of QC

- **Faster** calculations
- Perform detailed **search** more quickly
  - search in a database
  - traveling salesman
- **simulate** molecules for improvement of:
  - medical properties
  - superconductor
  - nanotechnology
- **Quantum cryptography**
  - credit cards
  - military secrets
  - Shor’s algorithm
- lasers
- sensors

Video: 06 What is a QC + applications, (stop at: 3 min. 13 sec.)
Atom Chip

- Height
- Skin depth
- Metal slab
- Spin frequency
New World Record

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Basic research & theoretical physics in Molde
Physicists entangle a record-breaking 14 quantum bits

By John Matson | Apr 5, 2011 04:18 PM  |  5

Quantum information science is a bit like classroom management—the larger the group, the harder it is to keep everything together.

But to build a practical quantum computer physicists will need many particles working in synchrony as quantum bits, or qubits. Each qubit can be a 0 and a 1 simultaneously, vaulting the number-crunching power of a hypothetical quantum computer well past that of ordinary computers. With each qubit in a superposition, a quantum computer can manipulate an exponentially large quantity of numbers at once—\(2^n\) numbers for a system of \(n\) qubits. So each step toward generating large sets of qubits pushes practical quantum computing closer to reality.
Zoo of quantum optics systems
Zoo of quantum optics systems

Ions in magnetic traps: (quantum register)

collective modes
Atoms trapped in a cavity: (atoms are qubits)
Optical lattice as array of microtraps for atoms:
Decoherence

(loss of superposition, loss of ordering)
Spin Decoherence in Superconducting Atom Chips

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(Received 25 March 2006; published 16 August 2006)

Using a consistent quantum-mechanical treatment for the electromagnetic radiation, we theoretically investigate the magnetic spin-flip scatterings of a neutral two-level atom trapped in the vicinity of a superconducting body. We derive a simple scaling law for the corresponding spin-flip lifetime for such an atom trapped near a superconducting thick slab. For temperatures below the superconducting transition temperature $T_c$, the lifetime is found to be enhanced by several orders of magnitude in comparison to the case of a normal conducting slab. At zero temperature the spin-flip lifetime is given by the unbounded free-space value.

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Spin Decoherence in Superconducting Atom Chips
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Coherent manipulation of matter waves is one of the ultimate goals of atom optics. Trapping and manipulating cold neutral atoms in microtraps near surfaces of atomic chips is a promising approach towards full control of matter waves on small scales [1]. The subject of atom optics is making rapid progress, driven both by the fundamental interest in quantum systems and by the prospect of new devices based on quantum manipulations of neutral atoms.

With lithographic or other surface-patterning processes complex atom chips can be built which combine many traps, waveguides, and other elements, in order to realize controllable composite quantum systems [2] as needed, e.g., for the implementation of quantum information devices [3]. Such microstructured surfaces have been highly successful and form the basis of a growing number of experiments [4]. However, due to the proximity of the cold atom cloud to the macroscopic substrate additional decoherence channels are introduced which limit the performance of such atom chips. Most importantly, Johnson-noise induced decoherence in atomic chips can be completely diminished by using superconductors instead of normal metals.

We begin by considering an atom in an initial state $|i\rangle$ and trapped at position $r_0$ in vacuum, near a dielectric body. The rate of spontaneous and thermally stimulated magnetic spin-flip transition into a final state $|f\rangle$ has been derived in Ref. [10],

$$\Gamma^s = \frac{\mu_B}{\hbar} \sum_{j} \langle f | \hat{J}_z | j \rangle \langle j | \hat{J}_z | i \rangle \times \text{Im} \left[ \nabla \times \nabla \times G(r_0, r_0, \omega) \right]_{j} \delta_{n_0 + 1}. \quad (1)$$

Here $\mu_B$ is the Bohr magneton, $g_j = 2$ is the electron spin $g$ factor, $\langle f | \hat{J}_z | j \rangle$ is the matrix element of the electron spin operator corresponding to the transition $|j\rangle \rightarrow |f\rangle$, and $G(r_0, r_0, \omega)$ is the dyadic Green tensor of Maxwell’s theory. Equation (1) follows from a consistent quantum-mechanical treatment of electromagnetic radiation in the

...
presence of absorbing bodies [11,12]. Thermal excitations of the electromagnetic field modes are accounted for by the factor $(\hbar_0 + 1)$, where $\hbar_0 = \sqrt{1/(e^\omega_0/\hbar - 1)}$ is the mean number of thermal photons per mode at frequency $\omega$ of the spin-flip transition. The dyadic Green tensor is the unique solution to the Helmholtz equation

$$\nabla \times \nabla \times G(r, r', \omega) = k^2 e(r, \omega)G(r, r', \omega) - \delta(r - r') I,$$

(2)

with appropriate boundary conditions. Here $k = \omega/c$ is the wave number in vacuum, $c$ is the speed of light and $I$ the unit dyad. This quantity contains all relevant information about the geometry of the material and, through the electric permittivity $\varepsilon(r, \omega)$, about its dielectric properties.

The current density in superconducting media is commonly described by the Mattis-Bardeen theory [13]. To simplify the physical picture, let us limit the discussion to low but nonzero frequencies $0 < \omega \ll \omega_0 = 2\Delta(0)/h$, where $\omega$ is the angular frequency and $\Delta(0)$ is the energy gap of the superconductor at zero temperature. In this limit, the current density is well described by means of a two-fluid model [14,15]. At finite temperature $T$, the current density consists of two types of carriers, superconducting Cooper pairs and normal conducting electrons. The total current density is equal to the sum of a superconducting current density and a normal conducting current density, i.e., $\mathbf{j}(r, t) = \mathbf{j}_s(r, t) + \mathbf{j}_n(r, t)$. Let us furthermore assume that the superconducting as well as the normal conducting part of the current density responds linearly and locally to the electric field [16], in which case the current densities are given by the London equation and Ohm’s law, respectively,

$$\frac{d\mathbf{j}_s(r, t)}{dt} = \frac{\varepsilon(r, t)}{\mu_0 \sigma_s(T)} \mathbf{E}(r, t),$$

$$\frac{d\mathbf{j}_n(r, t)}{dt} = \sigma_n(T) \varepsilon(r, t) \mathbf{E}(r, t).$$

(3)

The London penetration length and the normal conductivity are given by,

$$\lambda_\text{L}^2(T) = \frac{\mu_0}{\sigma_n(T)},$$

$$\sigma_n(T) = \frac{n_s(T)}{n_0} \sigma.$$  

(4)

Here $\sigma$ is the electrical conductivity of the metal in the normal state, $n$ is the electron mass, $e$ is the electron charge, and $n_s(T)$ and $n_n(T)$ are the electron densities in the superconducting and normal state, respectively, at a given temperature $T$. Following London [14], we assume that the total density is constant and given by $n_0 = n_s(T) + n_n(T)$, where $n_s(T) = n_0$ for $T = 0$ and $n_n(T) = n_0$ for $T > T_c$. For a London superconductor with the assumptions as mentioned above, the dielectric function $\varepsilon(\omega)$ in the low-frequency regime reads

$$\varepsilon(\omega) = 1 - \frac{1}{k^2 \lambda_\text{L}^2(T)} + i \frac{2/\varepsilon(\omega)\sigma(\omega)}{k^2 \delta^2(T)}$$

(5)

where $\delta(T) = \sqrt{2/\mu_0 \sigma(\omega)}$ is the skin depth associated with the normal conducting electrons. The optical conductivity corresponding to Eq. (5) is $\sigma(T) = 2/\mu_0 \varepsilon(\omega) \delta^2(T) + i/\omega \mu_0 \lambda_\text{L}^2(T)$.

In the following we apply our model to the geometry shown in Fig. 1, where an atom is located in vacuum at a distance $z$ away from a superconducting slab. We consider, in correspondence to recent experiments [5–7], $^{87}$Rb atoms that are initially pumped into the $|S_\text{e}J_z = 2, m_r = 2\rangle \rightarrow |2, 2\rangle$ state. Fluctuations of the magnetic field may then cause the atoms to evolve into hyperfine sublevels with lower $m_r$. Upon making a spin-flip transition to the $m_r = 1$ state, the atoms are more weakly trapped and are largely lost from the region of observation, causing the measured atom number to decay with rate $\Gamma_\text{DD}$ associated with the rate-limiting transition $|2, 2\rangle \rightarrow |2, 1\rangle$. The transition rate $\Gamma_\text{DD}^0 = \Gamma_\text{DD} + \Gamma_\text{DD}^\text{slab}$ can be decomposed into a free part and a part purely due to the presence of the slab. The free-space spin-flip rate at zero temperature is $\Gamma_\text{DD}^0 = \mu_0 \omega_c \delta^3 / (2\pi)^2$. The slab-contribution can be obtained by matching the electromagnetic fields at the vacuum-superconductor interface. With the same spin orientation as in Ref. [9], i.e., $|f|/|\delta_z(0)|^2 = |f(\delta_z)|^2$ and $|f(\delta_z)| = 0$, the spin-flip rate is $\Gamma_\text{DD}^\text{slab} = \Gamma_\text{DD}^0 (\tilde{I}_\parallel + \tilde{I}_\perp)$, with the atom-spin-orientation dependent integrals

$$\tilde{I}_\parallel = \frac{3}{8} \text{Re} \left( \int_0^\infty dq \frac{q^2}{\hbar_0} e^{i\omega_0 qz} \mathbf{r}_s(q) - \mathbf{r}_n(q) \right),$$

$$\tilde{I}_\perp = \frac{3}{8} \text{Re} \left( \int_0^\infty dq \frac{q^2}{\hbar_0} e^{i\omega_0 qz} \mathbf{r}_s(q) \right).$$

(7)

The electromagnetic field polarization dependent Fresnel coefficients

$$r_s(q) = \frac{\tilde{r}_s(q) - \tilde{r}_n(q)}{\tilde{r}_s(q) + \tilde{r}_n(q)},$$

$$r_n(q) = \frac{\tilde{r}_s(q) - \tilde{r}_n(q)}{\tilde{r}_s(q) + \tilde{r}_n(q)}.$$

(8)

Here we have $\tilde{r}_s(q) = \sqrt{\tilde{r}_s(q) + \tilde{r}_s(q)}$ and $\tilde{r}_n(q) = \sqrt{\tilde{r}_n(q) + \tilde{r}_n(q)}$.

Fig. 1. Schematic picture of the setup considered in our calculations. An atom inside a magnetic microtrap is located in vacuum at a distance $z$ away from a thick superconducting slab, i.e., a semi-infinite plane. Upon making a spin-flip transition, the atom becomes more weakly trapped and is eventually lost.
particular, above the transition temperature \( T_c \), the dielectric function in Eq. (5) reduces to the well-known Drude form. Because of the efficient screening properties of superconductors, in most cases of interest the inequality \( \lambda_c(T) \ll \delta(T) \) holds. Assuming furthermore the near-field case \( \lambda_c(T) \ll z \ll \lambda \), where \( \lambda = 2\pi/k \) is the wavelength associated to the spin-flip transition, which holds true in practically all cases of interest, we can compute the integrals in Eqs. (6)–(8) analytically to finally obtain

\[
\Gamma_n = \Gamma_n^0 (\delta_n + 1) \left[ 1 + \frac{1}{2} \frac{1}{\delta^2} \frac{1}{\delta^2} \frac{1}{\delta^2} \right] (9)
\]

For a superconductor at \( T = 0 \), in which case there are no normal conducting electrons, it is seen from Eq. (9) that the lifetime is given by the unbounded free-space lifetime \( \tau_0 = 1/\Gamma_n^0 \).

Equation (9) is the central result of our Letter. To inquire into its details, we compute the spin-flip rate for the superconductor niobium (Nb) and for a typical atomic transition frequency \( v = \omega/2\pi = 560 \text{ kHz} \) [5]. We keep the atom-surface distance fixed at \( z = 50 \mu\text{m} \), and use the Gorter-Casimir \([13]\) temperature dependence

\[
\frac{n_s(z)}{n_0} = 1 - \frac{n_s(z)}{n_0} = \frac{1}{1 + \frac{T}{T_c}} \quad (10)
\]

for the superconducting electron density. Figure 2 shows the spin-flip lifetime \( \tau_s = 1/\Gamma_n \) of the atom as a function of temperature: over a wide temperature range \( \tau_s \) remains as large as \( 10^{-5} \) sec. In comparison to the normal-metal lifetime \( \tau_s \), which is obtained for aluminium with its quite small skin depth \( \delta = 110 \mu\text{m} \) and using the results of Refs. [9,10], we observe that the lifetime becomes boosted by almost 10 orders of magnitude in the superconducting state. In particular, for \( T = 0 \) the ratio between \( \tau_s \) and \( \tau_s \) is even \( 10^5 \). From the scaling behavior Eq. (9) we thus observe that decoherence induced by current fluctuations in the superconducting state remains completely negligible even for small atom-surface distances around \( 1 \mu\text{m} \), in strong contrast to the normal state where such decoherence would limit the performance of atomic chips.

The scaling behavior of the spin-flip rate Eq. (9) can be understood qualitatively on the basis of Eq. (1). The fluctuation-dissipation theorem \([11,12]\) relates the imaginary part of the Green tensor and \( \epsilon(\omega) \), by \( \Im \Delta_{nn} = \Im \epsilon(\omega) \), assuming a suitable real-space convolution, and allows to bring the scattering rate Eq. (1) to a form reminiscent of Fermi’s golden rule. The magnetic dipole of the atom at \( \mathbf{r}_A \) couples to a current fluctuation at point \( \mathbf{r} \) in the superconductor through \( G(\mathbf{r}, \mathbf{r}; \omega) \). The propagation of the current fluctuation is described by the dielectric function \( \epsilon(\omega) \), and finally a backaction on the atomic dipole occurs via \( G(\mathbf{r}, \mathbf{r}; \omega) \). For the near-field coupling under consideration, \( z < \lambda \), the dominant contribution of the Green tensor is \( |G| \sim 1/z^4 \), thus resulting in the overall \( z^{-4} \) dependence of the spin-flip rate Eq. (9).
fied if using a more refined theory for the description of the superconductor. Our theoretical approach is valid in the same parameter regime as London’s theory, that is $\Delta(T) \gg \xi(T)$. It is well known that nonlocal effects modify the London length in Nb from $\lambda_{\text{L}}(0) = 35 \text{ nm}$ to $\lambda_{\text{L}}(0) = 90 \text{ nm}$ [17], and the coherence length $\xi(0)$, according to Peierls’s theory [18], from the BCS value $\xi_0$ to $1/\xi_{\text{a}}(0) = 1/\xi_{\text{a}}(T) + 1/\alpha_{\text{a}}(T)$, where $\alpha_{\text{a}}$ is of the order one and $l(0)$ is the mean free path. For Nb, $\xi_0 = 39 \text{ nm}$ and $l(0) \approx 9 \text{ nm}$ [19], and the London condition $\Delta(T) \gg \xi(T)$ is thus satisfied. Furthermore, at the atomic transition frequency the conductivity is $\sigma = 2 \times 10^7 \text{ (}\Omega \cdot m\text{)}^{-1}$ [20] and the corresponding skin depth is $\delta = \sqrt{\epsilon_0/\mu_0\sigma} = 15 \text{ mm} \ll \xi(T)$, such that Ohm’s law is also valid since $\Delta(T) \gg \xi(T)$ [21]. It is important to realize that other possible modifications of the parameters used in our calculations, as, e.g., a modification of Eq. (10) for $T$/$T_\text{c} < 0.5$ [22,23] will by no means drastically change our findings, which only rely on the generic superconductor properties of the efficient screening and the opening of the energy gap, and that our conclusions will also prevail for other superconductor materials.

We also mention that for both a superconductor at $T = 0$ and a perfect normal conductor, i.e. $\delta = 0$, the lifetime is given by the unbounded free-space lifetime $\tau_0$. In passing, we notice that for an electric dipole transition and for a perfect normal conductor, as, e.g., discussed in Refs. [24], the correction to the vacuum rate is in general opposite in sign as compared to that of a magnetic dipole transition. Elsewhere decay processes in the vicinity of a thin superconducting film will be discussed in detail [25].

To summarize, we have used a consistent quantum theoretical description of the magnetic spin-flip scatterings of a neutral two-level atom trapped in the vicinity of a superconducting body. We have derived a simple scaling law for the corresponding spin-flip lifetime for a superconducting thick slab. For temperatures below the superconducting transition temperature $T_c$, the lifetime has been found to be enhanced by several orders of magnitude in comparison to the case of a normal conducting slab. We believe that this result represents an important step towards the design of atomic chips for high-quality quantum information processing.

We are grateful to Heinz Krenn for helpful discussions. This work has been supported in part by the Austrian Science Fund (FWF).

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[16] Strictly speaking, a local dielectric response is only valid for a given temperature $T$, the skin depth $\delta(T)$ associated with the normal conducting part of the current density is sufficiently large in comparison to the mean free path $l(T)$ of the electrons and the penetration depth $\lambda(T)$ of the field large in comparison to the superconductor coherence length $\xi(T)$. Superconductors satisfying the latter condition are known as London superconductors.
Lifetime of an Atom Chip

Atom

$H$

dielectric body

vacuum

$z$

vacuum
Lifetime of an Atom Chip

Diagram showing an atom located above a dielectric body and the vacuum layers.

Graph illustrating the lifetime of an atom versus $T/T_c$ for different scenarios:
- Free space lifetime
- Superconductor ( Nb )
- Superconductor ($\lambda \times 3$)
- Normal metal (Al)

Note: The graph shows the lifetime on a logarithmic scale, with the $T/T_c$ ratio on the x-axis and lifetime in seconds on the y-axis.
Collaborators

Currently am I working with the following persons:

Prof. Bo-Sture Skagerstam, NTNU / CAS Oslo / Gøteborg

Asle Heide Vaskinn, Ph. D. student, NTNU

Arne Løhre Grimsmo, Ph. D. student, University of Auckland, New Zealand
video conferencing

screen sharing

FTP server in Molde:
need good up- and download speed

collaborators:
Göteborg / Oslo / Trondheim / New Zealand / England
Solution: Istad fiber
Research and development (R&D)

R&D:
- future-oriented, longer-term activities in science or technology
- using similar techniques to scientific research
- no predetermined outcomes
- with broad forecasts of commercial yield

USA:
- typical ratio of R&D: 3.5% of revenues
- high technology company: (computer manuf.) 7%

Germany:
- Siemens, 2011: 5.3% of revenues (3.925 billion euro)
Symphony of Science

[Morgan Freeman]
So, what are we really made of?
Dig deep inside the atom
and you'll find tiny particles
Hold together by invisible forces

Everything is made up
Of tiny packets of energy
Born in cosmic furnaces

[Frank Close]
The atoms that we're made of have
Negatively charged electrons
Whirling around a big bulky nucleus

[Mitchio Kaku]
The Quantum Theory
Offers a very different explanation
Of our world

[Brian Cox]
The universe is made of
Twelve particles of matter
Four forces of nature
That's a wonderful and significant story

[Richard Feynman]
Suppose that little things
Behaved very differently
Than anything big

Nothing's really as it seems
It's so wonderfully different
Than anything big

The world is a dynamic mess
Of jiggling things
It's hard to believe

[Kaku]
The quantum theory
Is so strange and bizarre
Even Einstein couldn't get his head around it

[Cox]
In the quantum world
The world of particles
Nothing is certain
It's a world of probabilities

(refrain)

[Feynman]
It's very hard to imagine
All the crazy things
That things really are like

Electrons act like waves
No they don't exactly
They act like particles
No they don't exactly

[Stephen Hawking]
We need a theory of everything
Which is still just beyond our grasp
We need a theory of everything, perhaps
The ultimate triumph of science

(refrain)

[Feynman]
I gotta stop somewhere
I'll leave you something to imagine

Video: 08 Symphony, (3 min. 29 sec.)
Summary

- Fundamental research
  - awareness of research and development
  - long term basis

- Example: Quantum optics
  - quantum computers
  - search more quickly
  - simulate molecules
  - quantum cryptography

- Istad fiber makes it possible with an international collaboration, living in Molde
Thank you for the attention!