Fermions de Majorama

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Conteudo

Materia e Antimateria

P. Dirac (1902-1984).

Equação de Dirac (1928)

$$(i\gamma^\mu \partial_\mu - m)\psi = 0$$

Conjugação de Carga

$$\psi^c = \eta_\psi C \psi^T$$

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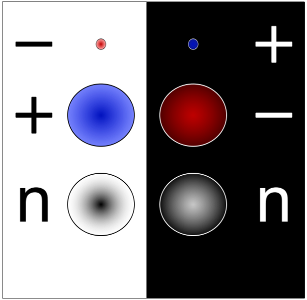
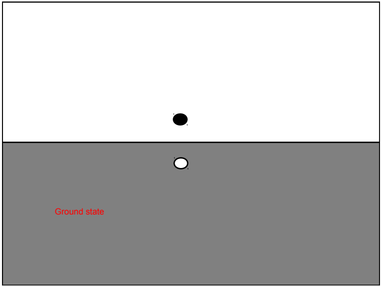


Partículas e antipartículas.



Mar de eletrons con energia negativa.

Majorana Fermions

E. Majorana (1906-c.a 1938)

Matrices de Majorana

$$\begin{aligned}\gamma^0 &= \sigma_2 \otimes \sigma_1\\ \gamma^1 &= i\sigma_1 \otimes 1\\ \gamma^2 &= i\sigma_3 \otimes 1\\ \gamma^3 &= \sigma_2 \otimes \sigma_2\end{aligned}$$

Particula=Antiparticula

$$\psi^c = \psi$$

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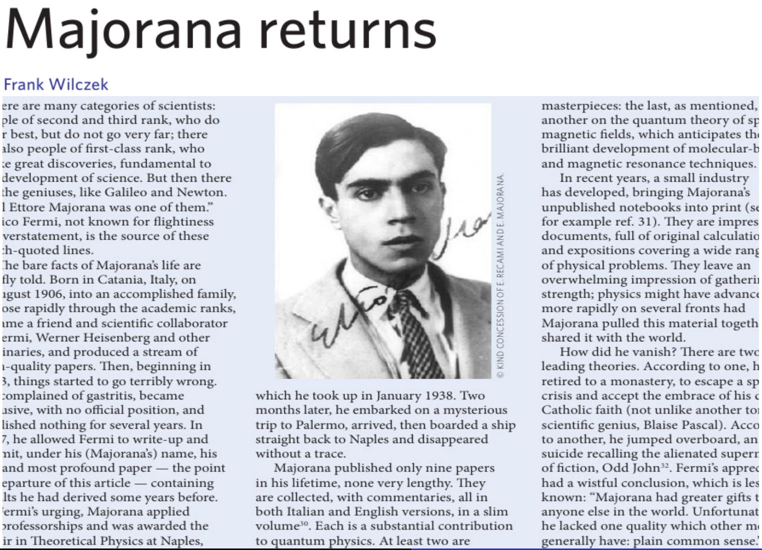
Fermions de Majorana em Materia condensada



Majorana returns

Frank Wilczek

ere are many categories of scientists: ple of second and third rank, who do r best, but do not go very far; there also people of first-class rank, who e great discoveries, fundamental to development of science. But then there the geniuses, like Galileo and Newton. l Ettore Majorana was one of them." ico Fermi, not known for flightiness verstatement, is the source of these h-quoted lines.

he bare facts of Majorana's life are fly told. Born in Catania, Italy, on gust 1906, into an accomplished family, ose rapidly through the academic ranks, me a friend and scientific collaborator ermi, Werner Heisenberg and other inaries, and produced a stream of -quality papers. Then, beginning in 3, things started to go terribly wrong. omplained of gastritis, became sive, with no official position, and lished nothing for several years. In 7, he allowed Fermi to write-up and nit, under his (Majorana's) name, his and most profound paper — the point eparture of this article — containing lts he had derived some years before. ermi's urging, Majorana applied rofessorships and was awarded the ir in Theoretical Physics at Naples, which he took up in January 1938. Two months later, he embarked on a mysterious trip to Palermo, arrived, then boarded a ship straight back to Naples and disappeared without a trace.

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Majorana published only nine papers in his lifetime, none very lengthy. They are collected, with commentaries, all in both Italian and English versions, in a slim volume[30]. Each is a substantial contribution to quantum physics. At least two are masterpieces: the last, as mentioned, another on the quantum theory of sp magnetic fields, which anticipates th brilliant development of molecular-b and magnetic resonance techniques.

In recent years, a small industry has developed, bringing Majorana's unpublished notebooks into print (se for example ref. 31). They are impres documents, full of original calculatio and expositions covering a wide rang of physical problems. They leave an overwhelming impression of gatheri strength; physics might have advanc more rapidly on several fronts had Majorana pulled this material togeth shared it with the world.

How did he vanish? There are two leading theories. According to one, h retired to a monastery, to escape a sp crisis and accept the embrace of his c Catholic faith (not unlike another to scientific genius, Blaise Pascal). Acco to another, he jumped overboard, an suicide recalling the alienated superr of fiction, Odd John[32]. Fermi's appre had a wistful conclusion, which is les known: "Majorana had greater gifts t anyone else in the world. Unfortunat he lacked one quality which other m generally have: plain common sense.

Fermions de Majorana em Materia condensada

Operadores fermionicos

$$c \; c^\dagger$$

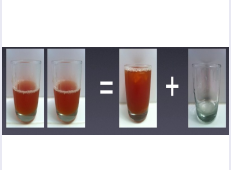
Partículas e buracos

Fermions de Majorana em Materia condensada

Operadores de Majorana

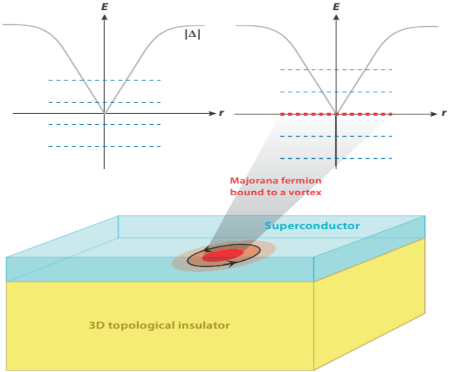
$$\begin{aligned}\gamma_1 &= \frac{1}{2}(c^\dagger + c)\\ \gamma_2 &= \frac{i}{2}(c^\dagger - c)\end{aligned}$$

Superposição



Dois Fermions de Majorana forman um Fermion normal

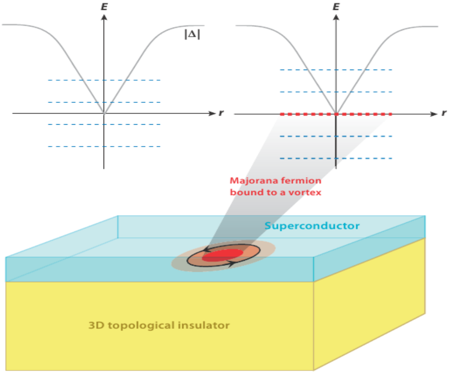
Fermiones de Majorana em Supercondutores



$$\gamma(E) = \gamma^{\dagger}(-E)$$

$$\gamma = \gamma^{\dagger}$$

Fermiones de Majorana em Supercondutores



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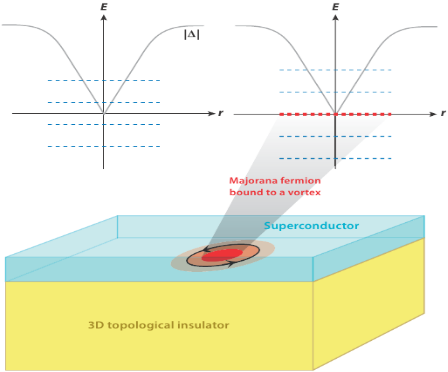
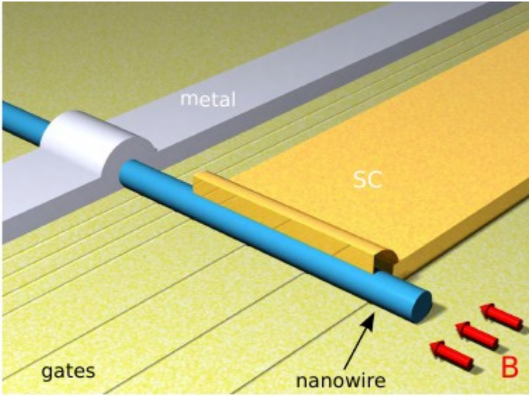
Fermiones de Majorana em Supercondutores



$$\gamma(E) = \gamma^\dagger(-E)$$

$$\gamma = \gamma^\dagger$$

Fermiones de Majorana em fios Quânticos



Nanofio ligado a um supercondutor e um metal normal

Fermions de Majorana em Materia condensada

Porque fios?

vantagens

- Fabricação.
- Menos excitações.
- Menor numero de graus de liberdade.

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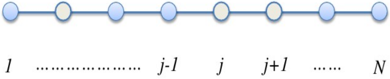
Cadeia de tight binding

$$H_1 = \sum_j [-w(c_j^\dagger c_{j+1} + c_{j+1}^\dagger c_j) - \mu(c_j^\dagger c_j - \frac{1}{2}) + \Delta(c_j c_{j+1} + \Delta c_{j+1}^\dagger c_j^\dagger]$$



Cadeia de tight binding

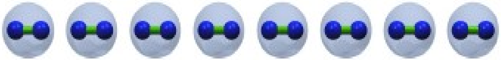
$$\begin{aligned}\gamma_{2j-1} &= exp(i\frac{\theta}{2})c_j + exp(-i\frac{\theta}{2})c_j^\dagger \\ \gamma_{2j} &= -iexp(i\frac{\theta}{2})c_j + iexp(-i\frac{\theta}{2})c_j^\dagger\end{aligned}$$

$$H_1 = \frac{i}{2}\sum_j[-\mu\gamma_{2j-1}\gamma_{2j}+(w+|\Delta|)\gamma_{2j}\gamma_{2j+1}+(-w+|\Delta|)\gamma_{2j-1}\gamma_{2j+2}]$$

fase (a)

$$|\Delta| = w = 0$$

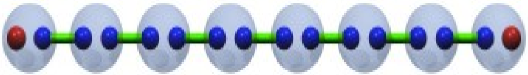
$$H_1 = \frac{i}{2}\sum_j [-\mu\gamma_{2j-1}\gamma_{2j}]$$



fase (b)

$$|\Delta| = w => 0$$

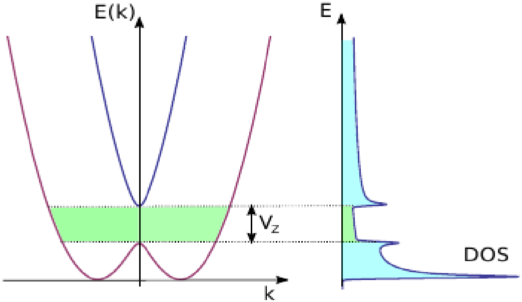
$$H_1 = iw \sum_j [-\mu \gamma_{2j} \gamma_{2j+1}]$$



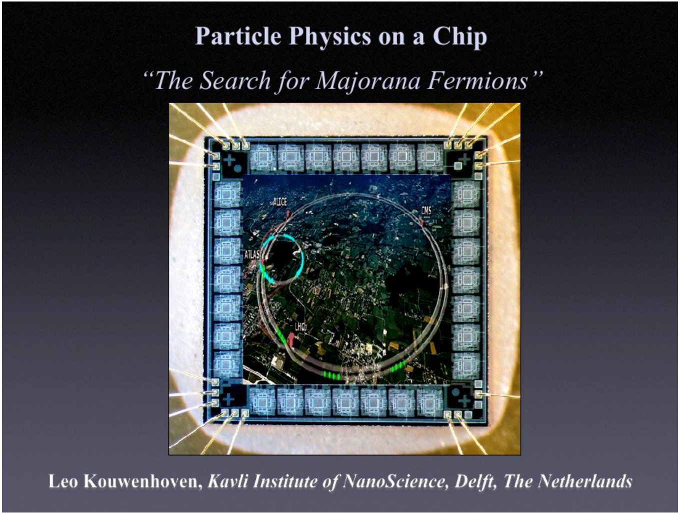
$$H_1 = \frac{i}{2}\sum_j [-\mu\gamma_{2j-1}\gamma_{2j} + (w+|\Delta|)\gamma_{2j}\gamma_{2j+1} + (-w+|\Delta|)\gamma_{2j-1}\gamma_{2j+2}]$$

$$H_{canonical} = \frac{i}{2}\sum_m \varepsilon_m b_m^1 b_m^2$$

$$\varepsilon(q) = \pm\sqrt{(2wcosq + \mu)^2 + 4|\Delta|^2 sin^2 q}$$



Espectro de excitação de um nanofio semiconductor

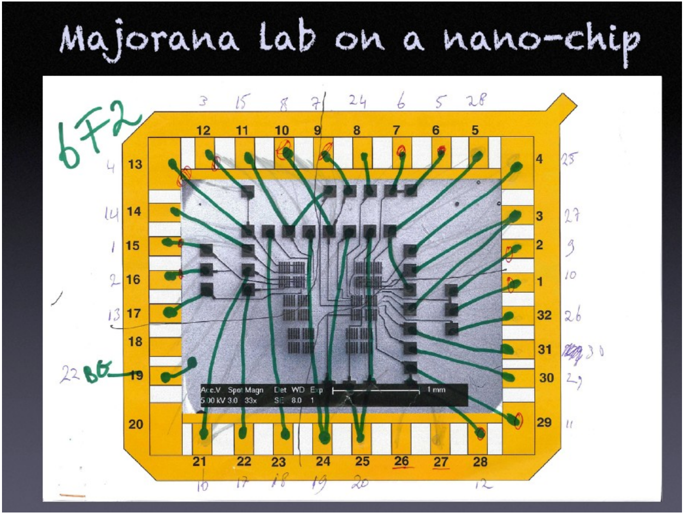


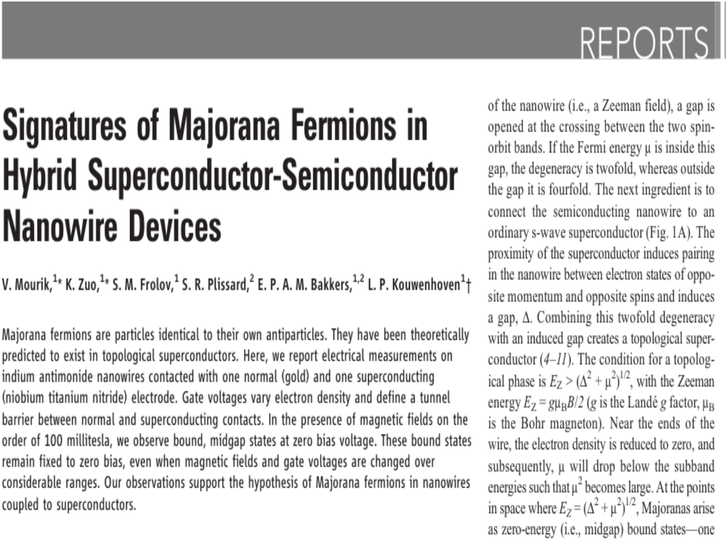
Particle Physics on a Chip

"The Search for Majorana Fermions"

Leo Kouwenhoven, *Kavli Institute of NanoScience, Delft, The Netherlands*

Underground Majorana lab


Majorana lab on a nano-chip
6F2
22 BG
12 11 10 9 8 7 6 5
3 15 8 7 24 6 5 28
13 14 15 16 17 18 19 20
4 14 1 2 13
4 3 2 1 32 31 30 29
25 27 9 10 26 30 29 11
21 22 23 24 25 26 27 28
16 17 18 19 20 12
Acc.V Spot Magn Det WD Exp
5.00 kV 3.0 33x SE 8.0 1
1 mm



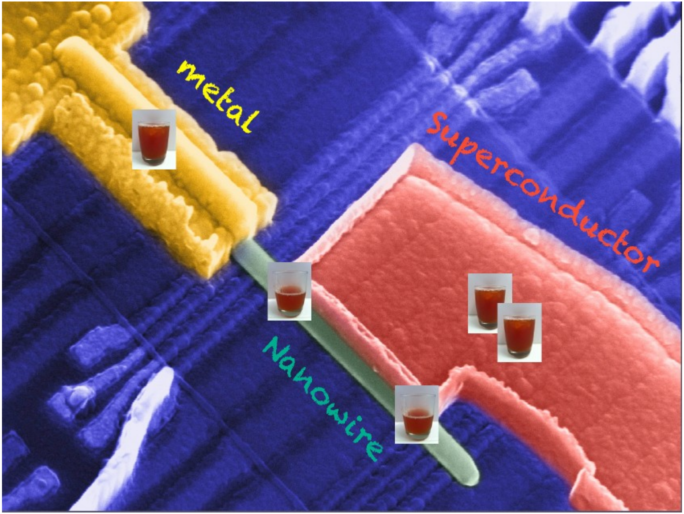
REPORTS

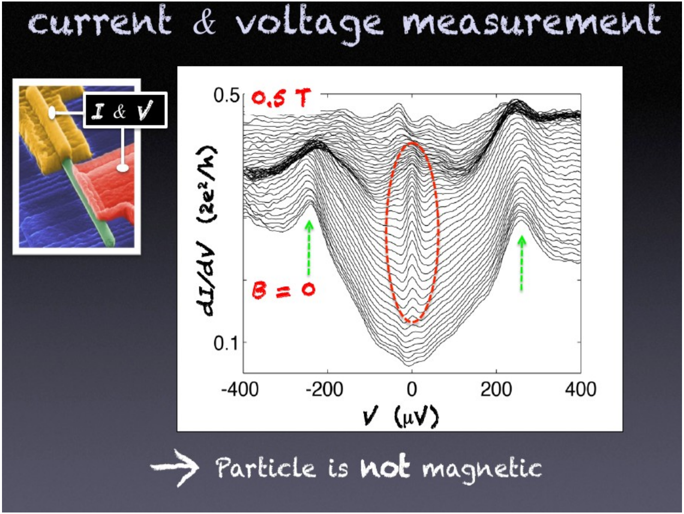
Signatures of Majorana Fermions in Hybrid Superconductor-Semiconductor Nanowire Devices

V. Mourik,[1]* K. Zuo,[1]* S. M. Frolov,[1] S. R. Plissard,[2] E. P. A. M. Bakkers,[1,2] L. P. Kouwenhoven[1]†

Majorana fermions are particles identical to their own antiparticles. They have been theoretically predicted to exist in topological superconductors. Here, we report electrical measurements on indium antimonide nanowires contacted with one normal (gold) and one superconducting (niobium titanium nitride) electrode. Gate voltages vary electron density and define a tunnel barrier between normal and superconducting contacts. In the presence of magnetic fields on the order of 100 millitesla, we observe bound, midgap states at zero bias voltage. These bound states remain fixed to zero bias, even when magnetic fields and gate voltages are changed over considerable ranges. Our observations support the hypothesis of Majorana fermions in nanowires coupled to superconductors.

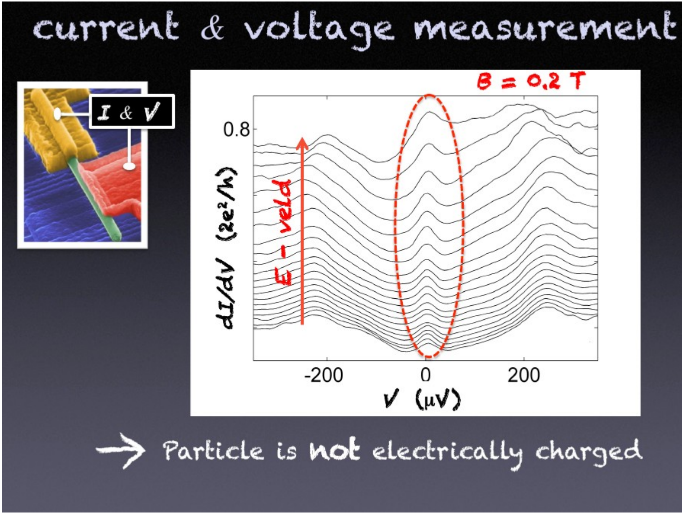
of the nanowire (i.e., a Zeeman field), a gap is opened at the crossing between the two spin-orbit bands. If the Fermi energy μ is inside this gap, the degeneracy is twofold, whereas outside the gap it is fourfold. The next ingredient is to connect the semiconducting nanowire to an ordinary s-wave superconductor (Fig. 1A). The proximity of the superconductor induces pairing in the nanowire between electron states of opposite momentum and opposite spins and induces a gap, Δ. Combining this twofold degeneracy with an induced gap creates a topological superconductor (*4–11*). The condition for a topological phase is $E_Z > (\Delta^2 + \mu^2)^{1/2}$, with the Zeeman energy $E_Z = g\mu_B B/2$ (g is the Landé g factor, μ_B is the Bohr magneton). Near the ends of the wire, the electron density is reduced to zero, and subsequently, μ will drop below the subband energies such that μ^2 becomes large. At the points in space where $E_Z = (\Delta^2 + \mu^2)^{1/2}$, Majoranas arise as zero-energy (i.e., midgap) bound states—one


metal
Superconductor
Nanowire



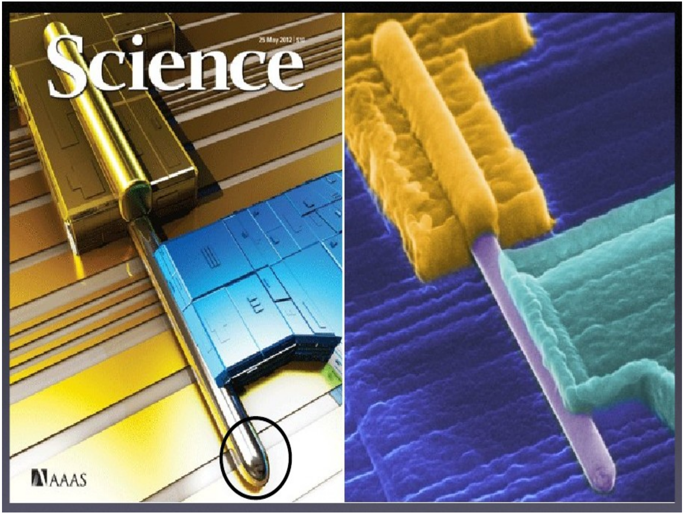
current & voltage measurement

→ Particle is **not** magnetic



current & voltage measurement

→ Particle is **not** electrically charged


Science
25 May 2012 | $10
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Ettore Majorana

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Despedida

¡Muito Obrigado!