Has Google managed to reach the critical value for the error rate of a single qubit?

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Abstract

Google claims that the error rate for the superconducting quantum computer called Willow is below the value of .1 percent meaning that the increase of the number of physical qubits in the logical qubits implies an exponential decrease of the error rate. This claim is however combined with an outlandish sounding claim about parallel universes, multiverses or multiple worlds being created in quantum computers. Taking the basic claim seriously, one can of course ask whether the slow error rate is actually theoretically possible in standard quantum mechanics or does it require new physics. These qubits are rather stable but are they so stable in standard QM?

In this article I will consider a TGD inspired model for Josephson junctions in which the long quantum coherence time for the superconducting qubits would be due to a large value of effective Planck constant. Also the question whether the confusing claim about multiple worlds could make sense in terms of the notion of many-sheeted space-time is posed.

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1 Introduction

Google claims to have achieved something marvellous with the quantum computer called Willow [**?**]. This claim is however combined with a totally outlandish sounding claim about parallel universes (multiverses or multiple worlds) being created in quantum computers and this has generated a lot of cognitive dissonance in professionals during the last week. They have not yet forgotten the earlier equally absurd claim about the creation of wormholes in quantum computers.

The Quanta Magazine article "Quantum Computers Cross Critical Error Threshold" (see this) tells what has been achieved but did not resolve the cognitive dissonance. I already commented the claims of Google in a blog posting (see this).

Now I encountered an excellent article "Ask Ethan: Does quantum computation occur in parallel universes?" (see this) analyzing thoroughly the basics of quantum computation and what Google has achieved. I recommend it to anyone seriously interested in quantum computation.

The really fantastic achievement is the ability to reduce the error rate for the physical qubits forming the grid defining the logical qubit below the critical value .1 percent guaranteeing that for larger grids of physical qubits the error rate decreases exponentially.

This achievement is more than enough! But why do they claim that this implies parallel universes? This claim is totally absurd and leads me to ask whether the claimed achievement is really true? How can one trust professionals who do not seem to understand the basic notions of quantum mechanics? On the other hand, the authors speak of multiple worlds. Is this confusing use of language intentional? What do they really mean? Multiverse or many worlds or something else? What comes to mind in the TGD framework, is many-sheeted space-time.

Taking the basic claim seriously, one can of course ask whether the slow error rate is actually theoretically possible in standard quantum mechanics or does it require new physics. These qubits are rather stable but are they so stable in standard QM?

I have been talking about this kind of new physics now for two decades. This new physics would play a key role in quantum biology and could be important also in condensed matter physics and even in chemistry. It is implied by the predicted hierarchy of effective Planck constants h_{eff} labelling the phases of ordinary matter with quantum scales scaled up by h_{eff}/h. This makes possible long scale temporal and spatial quantum coherence and can reduce the error rate and provide a solution to the basic problems listed in the article. The latest proposal along these lines is the proposal how classical computers and quantum computers could be fused to what might be regarded as conscious computers sharing several life-like features with biomatter [L5]. The situation is now different since the temperature is very low and the chip is superconducting. One learns from the video describing the Willow chip (see this) that the lifetime of a logical qubit is $T \sim 100$ μs. This time is surprisingly long: can one really understand this in ordinary quantum mechanics? One can try this in the TGD framework.

1. The energy of qubit flip must be as small as possible but above the thermal energy. Energy economics suggests that the Josephson energy $E = ZeV$ of electrons in Josephson junction is above the thermal energy at the temperatures considered but not much larger. For superconducting quantum computers (see this) the temperature is about 10^{-2} K, which corresponds to the energy scale of μeV.

2. One can try to estimate the value of h_{eff}. Josephson frequency $f_J = ZeV/h_{eff}$ gives a naive estimate for the quantum coherence time of a superconducting qubit as $T_J = h_{eff}/ZeV$. For $h_{eff} = h$ this gives $T \sim 3$ ns for the quantum coherence time of a single qubit. The value $h_{eff}/h \sim 3.3 \times 10^4$ would be needed to increase T from its naive estimate of $T = 3$ ns to the required $T = 100$ μs.

   The oscillation frequency of the Josephson junction as a non-linear analog of LC resonance circuit as $T \propto \sqrt{L_J C}$ defines a second candidate for the quantum coherence time T. For the flux qubits, the ratio of the coupling energy and Josephson energy scales is in the range 10-100 and suggests that the analog of circuit resonance period $T \propto \sqrt{L_J C}$ corresponds to the reported coherence time. This is indeed natural if quantum circuits are. in question. For $T = 100T_J$ 300 ns this would give $h_{eff}/h \sim 3.3 \times 10^2$.

3. I have proposed that these relatively small values of h_{eff} (as compared to the values of the gravitational Planck constant $\hbar gr$) can appear in electrically charged systems. The general criterion applying to all interactions is that the value of h_{eff} is such that the perturbation series as powers of, say, $Z_1 Z_2 e^2/\hbar_{eff}$ for the electromagnetic interactions of charges Z_1 and Z_2 converges.

   In the recent case, the value of h_{eff} could correspond to the electric counterpart of the gravitational Planck constant having the form $\hbar_{em} = Z_1 Z_2 e^2/\beta_0$, where $\beta_0 = v_0/c$ is a velocity parameter [L3]. Z_1 could correspond to a large charge and Z_2 to a small charge, say that of a Cooper pair. For instance, DNA having a constant charge density per unit length, would have a rather large value of $\hbar_{em}$. The presence of electronic Cooper pair condensate could give rise to the needed large electric charge making possible the needed value of $\hbar_{eff} = \hbar_{em} \sim 3.3 \times 10^4 \hbar$.

In the sequel the question whether the observed surprisingly long quantum coherence time for qubits be explained in terms of a large value of h_{eff} and whether the confusion notion of multiple worlds could correspond to many-sheeted space-time in the TGD framework.

2 General view of superconducting circuits

Superconducting circuits are quantum analogs of classical circuits. In quantum description urrent and voltage are replaced by amplitude modulus squared and phase. Phase and the number of Cooper pairs/total charge are canonically conjugate variables and therefore do not commute.

The model starts from a classical model and quantizes it using standard quantization rules ($p \rightarrow i\hbar d/dx$) meaning that the number of Cooper pairs (total charge) (or phase) is replaced by an operator proportional to $id/d\phi$ (id/dq). The wave functions are defined either in the discrete space Cooper pair numbers or in the space of the phases.

For the electrical elements of the classical one can assign parameters like effective inductance (counterpart of mass for ordinary particle) and inverse capacitance as counterpart of harmonic oscillator coupling strength. As far as circuit equations are considered, Josephson junction (see this) can be seen as an effective inductance. Generalized Kirchoff's laws hold true in the nodes of the circuit. If the electric resistance of the junctions can be neglected, Lagrangian formalism can be applied. This leads to the notion of Hamiltonian making possible the quantization of the circuit and computation of the energy spectrum of excitations.

Physically the Josephson junction is an insulating contact between two superconductors. Tunnelling however makes possible Josephson super currents. Non-linear dynamical inductance implies that the energy spectrum is not a harmonic oscillator spectrum.

Gravitational pendulum serves as an analog system for Josephson junctions. In absence of magnetic field there are 3 options correspond classically to small oscillations, critical situation, and over critical situation for which the pendulum rotates. All these cases correspond to coherent stats.

One can distinguish between 3 types of superconducting qubits corresponding to charge for which charge has well-defined valued, flux qubits and phase qubits. The ratio of coupling energy to the charging energy distinguishes between these special cases. In the case of flux qubits (see this and this), the critical value of an external magnetic field selects a single pair of levels defining a qubit for a given external magnetic field. These qubits have degenerate energies at criticality. The value of magnetic field selects the qubit value.

2.1 Modelling of Josephson junctions

Consider first a simple model for the dynamical variables and parameters of the Josephson junction.

1. Charge Q and the phase ϕ of the order parameter characterizing a coherent state appear as quantum conjugate variables. In a coherent state *resp.* charge eigen state ϕ *resp.* Q is well-defined unlike Q *resp.* ϕ.

   Magnetic flux is defined as

   $$\Phi = \Phi_0 \frac{\phi}{2\pi} \quad ,$$

   where ϕ is the phase difference over the Josephson junction (see this). Here $\Phi_0 = e^2/h$ is flux quantum.

2. The equation

$$V = \frac{\partial \Phi}{\partial t} = \frac{\Phi_0}{2\pi}\frac{\partial \phi}{\partial t}$$

expresses Faraday's law of induction. The change of the magnetic flux

$$\Delta\Phi = \int V dt$$

during time interval T corresponds to an integer multiple of the flux quantum.

3. The equation

$$I = I_c sin(\phi)$$

expresses current phase relation. I_c is the critical current above which the superconductivity fails. Q and V are classical variables and ϕ and modulus squared of the order parameter are quantum variables. They are related by quantum classical correspondence.

4. The time derivative of I gives

$$\frac{d\phi}{dt} = \frac{dI/dt}{I_c cos(\phi)} \ .$$

The substitution to the expression of V gives

$$V = L\frac{dI}{dt} \ , \quad L = \frac{\Phi_0}{2\pi I_c cos(\phi)} \ .$$

One can regard Josephson junction as an effective inductance $L \propto 1/cos(\phi)$. The analogy with harmonic oscillator L is analogous to mass and approaches infinite as ϕ approaches an odd multiple of $\pi/2$. At these critical points oscillatory motion transforms to a rotational motion.

5. One can identify two energy parameters and their ratio characterizes the Josephson junction. Coupling energy characterizes the insulator acting as a Josephson junction (see this). Coupling energy is the energy stored in Josephson junction when current passes through. Josephson energy obtained by using the classical analogy and defines a state variable, which does not depend on how the state is achieved:

$$E = \int Pdt = \int IVdt = I_c\frac{\Phi_0}{2\pi}\int sin(\phi)\frac{d\phi}{dt}dt = -E_J cos(\phi) \ ,$$

$$E_J = I_c\frac{\Phi_0}{2\pi} = L_J I_c^2 \ .$$

The parameter E_J is called the coupling energy. The parameter $L_J = \Phi_0/2\pi I_c$ Josephson inductance to be distinguished from the effective inductance $L = L_J/cos(\phi)$.

Charging energy $O_C^2/2C = Q_C V$ characterizes Josephson junction as a capacitor-like system. For charge qubits Q_C is quantized: $Q_C = n2e$.

The dynamics of the Josephson junction reduces to that of gravitational pendulum.

1. The circuit equation for a Josephson junction in the presence of external voltage V_0 is $V_L + V_C = V_0$, where one has $V_L + V_C = (\Phi_0/2\pi)d\phi/dt + Q/C$. One can transform the equation to an equation for Φ by taking time derivative an using the relation $I = I_c sin(\phi)$:

$$\frac{d^2\phi}{dt^2} + \omega^2 sin(\phi) = \frac{2\pi}{\Phi_0}\frac{dV_0}{dt} \ , \quad \omega^2 = \frac{1}{L_J C} = \frac{2\pi I_c}{\Phi_0 C} \ .$$

2. For a constant external voltage, the equation is mathematically equivalent with the equation of gravitational pendulum and is derivable from a Lagrangian and therefore allows quantization. System becomes critical as ϕ approaches an odd multiple of $\pi/2$. ω defines oscillation frequency, which is the second parameter besides Josephson frequency $\omega_J = 2eV/\hbar$.

   The ratio of these frequencies characterizes the Josephson junction. From the energy conservation $(d\phi/dt)^2/2 - \omega^2(cos(\phi) - 1) = E$ one obtains for the period

$$T = \int d\phi/\sqrt{2E + \omega^2(cos(\phi) - 1))} \ .$$

   For the critical situation the amplitude of oscillations approaches to $\phi_{max} = \pi/2$ and one has $E = \omega^2/2$. The value of T is finite since the integral at the upper end behaves as $1/\sqrt{\pi/2 - \phi}$.

2.2 Three different kinds of superconducting qubits

As already mentioned, there are three kinds of superconducting qubits.

1. Charge qubits correspond to the localization of the charge at the two sides of the junction. Charge is now a well-defined notion but one cannot speak of a propagating wave with a well-defined phase. This is like a transition from a momentum representation to a position representation. I have understood that the Willow processor and its predecessors use charged qubits. Charge qubits correspond to Josephson junctions which act like quantum wells having size of a few nanometers. In this case the ratio of the coupling energy to the charging energy is smaller than one.

2. If the coupling energy is much larger than charging energy, there is very small Josephson current through the junction and super currents flow in opposite directions along the loops defining the flux qubit (see this and this) without charge tunnelling. For the flux qubits the coupling energy is by 10-100 higher than charging energy.

   The two directions of current correspond to the values of the flux qubit. Decoupling of loops takes place. From the expression $I_c sin(\phi)$ of the Josephson current it is clear that ϕ should be near $(2n+1)\pi$ to make possible the coupling of the qubits. Small oscillations around these values correspond to approximate decoupling. Coupling energy is proportional to $cos(phi)$, has indeed large magnitude in this case.

3. For the phase qubits, where phase corresponds to the phase of the superconducting order parameter, the coupling energy is about 10^6 times larger than the charging energy. In this situation the charging energy $2eV$ per Cooper pair is proportional to $\partial_t\phi$ and approaches zero at the criticality $\phi = \pi/2$ as the analogy with gravitational pendulum makes clear. Classically this the large inertia implied by the large Josephson inductance L_J makes possible oscillation amplitudes approaching the critical value $\phi = \pi/2$ where $cos(\phi)$ is near zero. At the criticality the motions transform from oscillation to rotation or vice versa.

Some comments about flux qubits or persistent current qubits (see this and this) are in order. Computational operations are performed by pulsing the qubit with microwave radiation whose energy is near to the difference of the energy of the two flux qubit states. Note that microwave frequencies are in the range 1-100 GHz. The energies are in the range .01 -1 meV to be compared with the thermal energy about 1.5 μeV.

1. Two loops with micrometer scale are connected by Josephson junctions. $T \simeq 15$ mK must be below the critical temperature. The rate for the transfer of Cooper pairs via Josephson junctions connecting the loops must be small if the ratio of the coupling energy to charging energy is in the range 10-100. In this situation steady super currents wirth opposite directions flow in loops.

2. The is an integer number flux quanta of magnetic total flux through the loop. External magnetic field with half integer flux forces the inherent flux to be half-odd integer. At criticality, the two nearby energy states with inherent flux quanta, say n and $n + 1$, have

the same energy and the degenerate states can appear in superposition. The variation of the magnetic field selects either option by energy minimization. Also microwave photons can flip the flux qubits.

The opposite supercurrents flowing in the loops is about 300 nA (A=$6.241509074 \times 10^{18}$ e/s making about 10^{12} e/s: this is of the order electron charge per electron Compton time).

3. Higher flux quanta are eliminated by modifying the excitation spectrum so that it is not integer valued oscillator spectrum anymore. The kinetic nature of the Josephson inductance introduces the non-linearity.

3 TGD based model for the Josephson junction

The long quantum coherence time of the charge qubit in the Willow processor suggests that new physics might be involved. Also the weird sounding talk about parallel worlds and similar things suggests that the authors do not tell all that they know of.

3.1 Is a large value of effective Planck constant needed to explain the findings?

The long quantum coherence time essential for the low error rate suggests the possibility of a large value of effective Planck constant. Large values of h_{eff} would be natural at quantum criticality characterized by long range quantum fluctuations.

One can consider two kinds of quantum criticalities.

1. The first kind of quantum criticality would be associated with a transition between oscillatory and rotational motions for the analog of gravitational pendulum as an analog of Josephson junction and the deviation of the oscillation amplitude from $\pi/2$ would characterize the criticality. In this situation Josephson current and therefore charge transfer between the loops would become large.

   One can solve the energy eigenstates of the system. The situation corresponds to a periodic potential proportional to $1 - cos(\phi)$ so that also a motion in the lattice serves as an analog. One expects a bound state spectrum as analog harmonic oscillator spectrum energies below $E = \omega^2/2$ plus states in which the system performs rotation. These states would correspond to a continuous spectrum consisting of the analogs of conduction bands.

2. Second kind of quantum criticality can occur for the charge and flux qubits and occurs in the presence of an external magnetic field having a flux, which is near half odd integer multiple of Φ_0. This kind of magnetic field could play an essential role in the control of the system by inducing transitions between two nearby bound states. At the criticality the energies of these states become degenerate in the resolution defined by thermal energy. The situation would be very similar to that discussed in [L5], where a classical electric field would control the flip energy of quantum gravitational OH-O^- qubits. The Willow processor could be near to this kind of quantum criticality.

The notion of effective Planck constant was originally introduced for cyclotron states to explain the findings of Blackman and others [J1].

1. The cyclotron energies for the electrons could play a significant role also here and quantum criticality could correspond to a value of $h_{eff} > h$ increasing the scale of the cyclotron energy above the thermal energy. Note that the temperature must be below the critical temperature for the transition to super-conductivity.

2. The size scale of the flux quantum is of order micrometer and the condition that the external magnetic flux is $(2n + 1)\Phi_0/2$ determines the cyclotron energy scale of electrons. The "endogenous" magnetic field of $B_{end} = .2$ Gauss explains the findings of [J1] and led to the notion of h_{eff} phases of ordinary matter as an analog of dark matter. TGD suggests an interpretation of B_{end} in terms of monopole flux tubes. For B_{end} electron cyclotron frequency

is $f_c = 6 \times 10^5$ Hz, which corresponds to energy of 6×10^{-9} eV whereas the thermal energy is about 10^{-6} eV. The cyclotron energy exceeds thermal energy if the value of h_{eff}/h is $10^3/6 \simeq 167$.

3. Magnetic length $l_B = \sqrt{\hbar/eB}$ equals to $25/\sqrt{B/Tesla}$ nm. B_{end} corresponds to $l_B \simeq= 5.590$ μm. Magnetic length l_B as an estimate or the flux tube radius corresponds for $l_B = 1$ μm to $B = 30B_{end} \simeq 6$ Gauss. Cyclotron energy in this case is 1.8×10^{-7} eV. The cyclotron energy exceeds thermal energy if the value of h_{eff}/h is $10^3/180 \simeq 5.6$.

4. $h_{eff}/h = n > 1$ phase has two interpretations.

   (a) Space-time surface is an n-sheeted covering of M^4 in CP_2 degrees of freedom. For this option one does not expect very large values of n.

   (b) Space-time surface is an n-sheeted covering of CP_2 in M^4 degrees of freedom. For this option the n sheets would correspond to the monopole flux tubes forming a bundle-like structure assignable to the flux qubits. The value of n could be very large for the gravitational Planck constant originally introduced by Nottale [E1] [L2] and also electric Planck constant [L3].

   Cooper pairs could be associated with different sheets of the covering and the scaling of the cyclotron energy would correspond to the existence of a quantum coherent structure with $n = h_{eff}/h$ sheets as a geometric counterpart of a Bose-Einstein condensate of Cooper pairs.

This picture brings to mind the confusing claim of the Google group that indications for multiple worlds have been observed: could they correspond to many-sheeted space-time in the TGD framework?

3.2 The relation to the TGD based model of neuronal membrane

The proposed model for the findings of Google group are partially inspired by the TGD view of nerve pulse [L4], which assumes a sequence of Josephson junctions along the axonal membrane assigned with the membrane proteins acting as ion channels. The temperature in this case is physiological temperature, The effective Planck constant is very large now and possible identification is as the gravitational Planck constant $\hbar_{gr}$ [E1] for the Earth. The large value of $\hbar_{gr}$ increases the Josephson period $T_J = h_{gr}/ZeV$ even to the scale of EEG frequencies. The monopole flux tubes through the Josephson junction are also in a key role and I prefer to talk about generalized Josephson junctions. Josephson energy $E_J = ZeV$ is replaced with its sum with the difference of cyclotron energies at the two sides of the membrane.

The two sides of the cell membrane/lipid layers are in a role similar to that of flux tubes and one can imagine that opposite supra currents at the two sides are present and consist of various dark ions with a large h_{eff} as the model for the findings of Blackman and others leads to propose [L4]. The possible role of dark positively charged ions in making a living system analogous to a quantum computer is discussed in [L5]. The vision predicts that any cold plasma could have life-like properties.

The TGD based model of neuronal membrane is in terms of Josephson junctions. For the resting states, the phase of the order parameter is well-defined. The model allows two kinds of solutions corresponding to a propagating mode which is either oscillatory or rotational. The rotational mode gives rise to a sequence of Sine-Gordon solitons. The possible transition occurring between these modes would mean flip of phase qubit. I have proposed that the soliton sequence corresponds to the resting state but one cannot exclude the possibility that oscillation is in question. Also the possibility that both modes are possible and code for phase qubits can be considered. The second option is that the distinction between neurons and ordinary cells could correspond to the distinction between rotation and small oscillation. Very small oscillation amplitudes around $\phi = 0$ could correspond to flux qubits.

Could nerve pulse conduction correspond to a local charge flow along the molecular junction and mean a local failure of quantum coherence in long scales. The proposed model based on the analogy of Josephson junction with gravitational pendulum suggests that nerve pulse corresponds to a propagation of a perturbation changing the direction of rotation for some Josephson junctions.

Zero energy ontology (ZEO. [L1, L6]) suggests that quantum tunnelling corresponds to a pair of "big" state function reductions (BSFRs) involving temporary change of the arrow of time. I have proposed that nerve pulse conduction corresponds to this kind of local event.

In the standard picture Josephson current should correspond to quantum tunneling. In the TGD framework Josephson current is assumed to correspond to a flow along monopole flux tubes connecting the two sides of the membrane [L4]. Could the ordinary oscillating Josephson current in the stationary situation accompanying the oscillation of the membrane potential correspond microscopically to less dramatic localized pairs of BSFRs in some scale? At the level of the nodel, these events are not localized and do not seem to correspond to flips of charge qubits. What about the miniature potentials of neuronal membranes in the meV range: could they correspond to localized events or perhaps to flips of flux qubits? What about the reported conduction of analogs of nerve pulses in the meV range [I1] in ordinary cell membranes?

If nerve pulse generation corresponds to a local transition to charged qubit phase, it should be caused by the reduction of the ratio of the coupling energy to the charging energy. Nerve pulse is generated below a critical membrane potential meaning a reduction of the charging energy. Also the coupling energy should be reduced.

REFERENCES

Cosmology and Astro-Physics

[E1] Nottale L Da Rocha D. Gravitational Structure Formation in Scale Relativity, 2003. Available at: https://arxiv.org/abs/astro-ph/0310036.

Biology

[I1] Adamatsky A. Language of fungi derived from electrical spiking activity, 2022. Available at: https://arxiv.org/pdf/2112.09907.pdf.

Neuroscience and Consciousness

[J1] Blackman CF. *Effect of Electrical and Magnetic Fields on the Nervous System*, pages 331–355. Plenum, New York, 1994.

Books related to TGD

Articles about TGD

[L1] Pitkänen M. Some comments related to Zero Energy Ontology (ZEO). Available at: https://tgdtheory.fi/public_html/articles/zeoquestions.pdf., 2019.

[L2] Pitkänen M. Comparison of Orch-OR hypothesis with the TGD point of view. https://tgdtheory.fi/public_html/articles/penrose.pdf., 2022.

[L3] Pitkänen M. About long range electromagnetic quantum coherence in TGD Universe. https://tgdtheory.fi/public_html/articles/hem.pdf., 2023.

[L4] Pitkänen M. Some new aspects of the TGD inspired model of the nerve pulse . https://tgdtheory.fi/public_html/articles/np2023.pdf., 2023.

[L5] Pitkänen M. Quartz crystals as a life form and ordinary computers as an interface between quartz life and ordinary life? https://tgdtheory.fi/public_html/articles/QCs.pdf., 2024.

[L6] Pitkänen M. TGD as it is towards the end of 2024: part II. https://tgdtheory.fi/public_html/articles/TGD2024II.pdf., 2024.