How can we go faster than quark computing: millicharged particles

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Abstract In many practical problems, there is a need for faster computations. One of such problems is designing an AI that would constantly re-train itself, just like a human brain does. Because physics restricts the speed of all communications to the speed of light, to drastically speed up computations, we need to drastically decrease the size of all computational units. Up to now, most actual and proposed ways to do it was to use only a part of what formed the previous computational cell: a few molecules instead of the whole cell, and atoms, elementary particles, and quarks instead of a few molecules. However, since quarks do not have sub-parts, we cannot use this approach to go faster than quark computing. A hope to go faster comes from the well-known problem of fundamental physics: if we naively compute such simple things as the overall energy of an electron, we get meaningless infinities. Physicists overcome this problem by applying a special mathematical trick called renormalization – but it is definitely desirable to come up with a more physically meaningful solution. In this paper, we show that a natural physical solution implies the exis-

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tence of special particles whose electric charge is much smaller than the electric charge of an electron. Due to the smallness of their electric charge, they have very little effect on the usual matter – while their mass contributes to the overall mass of the Universe. From this viewpoint, they are perfect candidates for mysterious dark matter – and indeed, this is where they were originally proposed, under the name of millicharged particles. These particles are much smaller than quarks, so the use of these particles can potentially enable us to further speed up computations even more than quark computing.

1 Formulation of the problem

We need faster computations. While current computers are much faster that ever, there are still many practical problems for which the current computation speed is not sufficient – in the sense that we have algorithms for computing the desired results, but even on the fastest high-performance computers, the corresponding computations require unrealistically astronomical time. These problems include predicting the path of a tornado, finding the best chemical that would defeat a virus without causing bad side effects, etc. In the last decades, many AI-related problems have been added to this list, such as designing an AI that would constantly re-train itself, just like a human brain does.

How can we speed up computations? One of the main limitations on computational speed is the fact that, according to Relativity Theory, the speed of all communications i limited by the speed of light, which is 300 000 km/sec; see, e.g., [2, 7]. This means, in particular, that in a usual laptop of size about 30 cm it takes about 1 nanosecond to move any signal from one part of the laptop to another. During this time, a usual 4 GigaHertz laptop already performs 4 arithmetic operations. Thus, the only way to drastically speed up computations is to make computational devices much smaller.

From current high-performance computers to quantum computing and to quark computing. In current computers, already the size of a memory cell is close to the size of a molecule. If we decrease this size even more, we will get to the level of molecules, then atoms, then elementary particles. At this size, we can no longer use Newtonian physics, we need to take into account quantum effects; computations that take quantum physics into account are known as *quantum computing*; see, e.g., [6].

Potentially, we can go even further and take into account that some elementary particles – specifically, protons, and neutrons – consist of subparticles known as *quarks*. In view of this, in [5], we proposed to use quarks for computations – specifically, we proposed to use techniques of *optical color computing* – that uses the 3-basic-color structure of visible light (see, e.g., [3, 4, 8, 9]) – to utilize the 3-color structure of quarks.

Comment. It is important to emphasize that the phrase "protons and neutrons consist of quarks" has a somewhat different meaning than a seemingly similar phrase "atoms consists of elementary particles": we can separate protons, neutrons, and electrons that form an atom, but we cannot separate quarks from each other.

Can we go faster than quark computing? At first glance, no. If quark computing speed will not be sufficient, what can we do? Up to this moment, the speed up was achieved by using smaller and smaller parts of the previously suggested computational device. However, we cannot do it to go beyond quarks, since, according to modern physics. there are no sub-particles within quarks.

But there is hope. In this paper, we show that it is, in principle, possible to go faster than quark computing. Specifically, it may be possible if we use so-called *millicharged particles*; see, e.g., [1] and references therein. Specifically, in this paper, we explain why these particles naturally appear, and how they can potentially speed up computations.

Structure of this paper. To explain why millicharged particles naturally appear, we first, in Section 2, remind the readers about the infinities problem in fundamental physics – one of the main challenges in theoretical foundations of quantum physics. In Section 3, we argue that the only physically meaningful way to solve this problem is to assume the existence of special particles known as *millicharged particles*. In Section 4, we explain possible observable effects of the existence of these particles – it turns out that they are perfect candidates for the so-called *dark matter* – and this is, by the way, why their existence was originally proposed. Finally, in a brief Section 5, we explain how these particles can speed up computations.

2 Infinities problem in fundamental physics – what it is, how it is solved, and what is the remaining challenge

Infinite answers in physics: the simplest case of a known problem. According to modern physics, the word consists of elementary particles – i.e., particles that cannot be further divided into independent parts. Most of the matter consists of electrons, protons, and neutrons – and protons and neutrons consists of quarks. Electromagnetic field consists of photons, other fields also consist of the corresponding particles.

Because of special relativity theory, an elementary particles must be point particles. Indeed, if such a particle would contain parts located at different spatial points, then, according to special relativity theory, these two parts will not be able to immediately affect each other and will be, in this sense, independent – which contradicts to the very definition of an elementary particle.

In particular, an electron is a point-wise particle. This leads to a very natural question: what is the overall energy of the electron? This seems to be a simple question: to compute the overall energy of an electron, you need to add its uncharged mass-related energy $m_0 \cdot c^2$ and the overall energy of the electric field generated by the electron. Somewhat surprisingly, the resulting energy turns out to be infinite; see, e.g., [2, 7] – which makes no physical sense, since energy is the ability to do work, and a tiny electron has only a very small such ability.

Let us explain this surprising conclusion in some detail. According to Coulomb's Law, the absolute value $\|\mathbf{E}(\mathbf{x})\|$ of the electric field $\mathbf{E}$ of a point-wise particle with electric charge q at a given point $\mathbf{x}$ is proportional to q/r^2: $\|\mathbf{E}(\mathbf{x})\| = C_1 \cdot q/r^2$ for some constant C_1, where r is the distance between the particle and the point $\mathbf{x}$. It is known that the energy density $\rho(\mathbf{x})$ of the electric field is proportional to its square $\|\mathbf{E}(\mathbf{x})\|^2$, so $\rho(\mathbf{x}) = C_2 \cdot \|\mathbf{E}(\mathbf{x})\|^2 = C \cdot r^{-4}$ for some constant C_2, where $C \stackrel{\text{def}}{=} C_2 \cdot c_1^2 \cdot q^2$. The compute the overall energy E of the electric field, we need to integrate the density over the whole space:

$$E = \int \rho(\mathbf{x})\,d\mathbf{x} = C \cdot \int r^{-4}\,\mathbf{x}.$$

We can compute this integral by taking into account that the function $\rho(\mathbf{x})$ is constant on each sphere of radius r with the center at the particle, and that the area of this sphere is equal to $(4/3) \cdot \pi \cdot r^2$. Thus,

$$E = C \cdot \int_{r=0}^{\infty} r^{-4} \cdot \frac{4}{3} \cdot \pi \cdot r^2\,dr = C \cdot \frac{4}{3} \cdot \pi \cdot \int_0^{\infty} r^{-2}\,dr.$$

The last integral is easy to compute:

$$\int_0^{\infty} r^{-2}\,dr = -\left.\frac{1}{r}\right|_{r=0}^{r=\infty} = \frac{1}{0} - \frac{1}{\infty}.$$

The first term is infinite, the second is 0, so overall energy is indeed infinite.

Comment. This physically meaningless infinite result is not the first such result derived from classical (pre-quantum) physics. The very first infinite result happened when scientists tried to compute the overall energy of the black body radiation. This first infinite result motivated Max Planck to conclude that the energy of the electromagnetic waves cannot take any possible real value – for each frequency, all possible energy values are proportional to some constant depending on this frequency. This conclusion – that started quantum physics – helped to find the finite value of the energy of the black body radiation. However, other infinities remain in the quantum physics, and the infinite overall energy of an electron is one of these remaining problems.

How this problem is resolved now: renormalization techniques. In general, an integral is a limit of sums – namely, of integral sums. In particular, the integral E over the whole 3D space can be viewed as the limit of integral sums $E(\varepsilon)$ over a grid formed by values $(x,y,z) = (n_x \cdot \varepsilon, n_y \cdot \varepsilon, n_z \cdot \varepsilon)$ with integer n_x, n_y, and n_z when ε tends to 0. For each $\varepsilon > 0$, the integral sum is finite, so we can find the value $m_0(\varepsilon)$ for which the corresponding approximation $m_0(\varepsilon) \cdot c^2 + E(\varepsilon)$ to the overall energy of an electron is exactly equal to its observed energy $m_e \cdot c^2$: it is sufficient to take $m_0(\varepsilon) = m_e - E(\varepsilon) \cdot c^{-2}$.

This is a particular case of a general class of procedures known as *renormalization*: we adjust parameters of the model for each ε so that in the limit, we get a finite result.

Renormalization: successes and limitations. Renomalization allowed physicists to come up with physically meaningful – and often experimentally confirmed – values of different physical quantities. The problem with this procedure is that it is largely a mathematical trick. It is desirable to come up with a more physically meaningful solution. This is what we are attempting to do in this paper.

Comment. At first glance, this be may more of a philosophical, methodological challenge. Indeed, we have numerical predictions that work well. If we simply package them in more physics-like form, we do not seem to gain any practical advantage.

This may be true in general, but in this particular case, we will show that a deeper physical analysis can potentially lead to new physical ideas, new observations, and – what is of the most interest to us – new faster computing schemes.

3 Millicharged particles naturally appear

To solve the infinite-energy problem, we need to have compensating charged particles. Infinities appear when we integrate around the charged point-wise particle. So, under the current laws of physics, the only way to avoid infinities is to make sure that at the location of the point-wise particle, there is no electric charge – i.e., for example, the the negative electric charge of an electron is somehow compensated by some other positive charge(s). Similarly, the positive charge of a particle – for example, of a positron – must be compensated by some other negative charge(s). These additional charges must appear no matter where in space we place the original charged particles. This means that everywhere, there should be plenty of such compensating charged particles – both negatively and positively charged.

The charge of the compensating particles should be smaller than the electron charge. What should be the electric charge of such particles? In general, with the exception of quarks – which are not available as independent particles anyway – all electric crharges are proportional to the electric charge q_0 of an electron. From this viewpoint, it seems natural to assume that the charge of the compensating particle should also be proportional to q_0.

Since we need this additional positive charge to full compenstae the negative charge $-q_0$ charge of the original electron, the compensating charge cannot be larger than q_0. So, this charge must be exactly equal to q_0. In this case, the charge at the original electron location is fully compensated by a positively charged compensating particle – and thus, a similar negative charge appears in the location where this compensating particle originally was. For this newly appearing charged particle, we face the same infinite-energy problem as before. This means that we cannot really solve the infinite-energy problem if we only consider compensating particles whose charge is larger than or equal to the electron charge.

Thus, to solve this problem, we need compensating particles whose electric charge is smaller than the charge of an electron.

The existence of such compensating particles indeed solves the infinite-energy problem. If we assume that such particles exist and are everywhere, then a negatively charged electron will attract positively charged compensating particles – and repel negatively charged ones. This will happen for all the compensating particles in the vicinity of an electron. This will not happen far away from the electron – there are always quantum fluctuations, and when the intensity q_0/r of the resulting weak field is smaller than these fluctuations level f, the field will not affect such particles. So, the attraction and repulsion are only felt when $q_0/r > f$, i.e. when $r < r_0 \stackrel{\text{def}}{=} q_0/f$.

So, in this simplifying approximation, the positively charged particles that were originally located at a distance $< r_0$ around the electrin fall down to the electron location – until they fully compensate the original electron charge. Similarly, all negatively charged particles in this vicinity move out from the zone where the field is potentially felt – until they reach the distance r_0 from the electron at which its electric field is no longer felt. As a result, the overall charge will be 0 in the r_0-vicinity of the electron, and the original negative charge will be concentrated around the sphere of radius r_0 around the electron. In this case, the electric field will be 0 inside this sphere and take on the usual Coulomb values for $r \geq r_0$. Thus, the integral proportional to the overall energy is no longer from 0 to infinity, it is from $r_0 > 0$ to infinity – and is, thus, finite. So, this indeed solves the infinite-energy problem.

The charge of the compensating particles must be much smaller than the electron charge. In this model, we assumed that the charge of a compensating particle is smaller that the charge of the original electron. How smaller should it be? Let us analyze this question. If the charge of the compensating particle is N times smaller than the electric charge q_0 of an electron, then N positively charged compensatory particles are needed to compensate the electrons charge. Thus, N negatively charged compensatory particles will be concentrated on the radius-r_0 sphere around the electron.

The original electric field of an electron is fully isotropic – which has been confirmed by numerous experiments. In contrast, the new configuration – several particles around the sphere – is not fully isotropic. As a result, its field is not fully isotropic. In the limit $N \to \infty$, the configuration and the field become isotropic. This means that the larger N, the closer the resulting field is to the isotropic one. Since, as we have mentioned, the observed field is close to isotropic, this means that N is large.

Thus, the charge of the compensating particles must be much smaller than the electron change.

Such particles have been proposed earlier. Such particles – whose electric charge is much smaller than the electric charge of an electrin – have been proposed earlier. They are called *millicharged* particles.

4 Additional effects of millicharged particles: they are perfect candidates for dark matter

Need for dark matter. The additional effect of millicharged particles is related to the need for dark matter. The need for dark matter comes from the fact that, based on the rotation speed of stars in many galaxies, the overall mass inside the galaxy is much larger than the overall mass of all visible objects in this galaxy. Whatever contributes to this additional mass is known as *dark matter*. Since the dark matter is not visible – the only visible thing is its mass – it has to have a very low level of interaction with the normal metter.

Millicharged particles are perfect candidates for dark matter. Indeed, since the electric charge of each of the new particles is very small, its interaction level with normal matter is very low. However, since these particles have mass, they contribute to the overall mass of each spatial area. From this viewpoint, these particles are a perfect candidate for dark matter.

This is exactly where they were originally proposed: as candidates for dark matter. Specifically, since dark matter should have very little interaction with normal matter, it was proposed that dark matter consist of particles with no electric charge. However, this model of dark matter turned out to be inconsistent with cosmological observation. These observation fit better with the assumption that dark matter particles have a very small electric charge.

5 Millicharged particles can potentially speed up computations

As we have mentioned in Section 1, there is a practical need for faster computations, and the natural way to drastically speed up computation is to drastically decrease the size of the cells used in a computational device. Up to now, the main idea was to use a part of what formed the original computational device: few molecules instead of the whole cell, an atom instead of a molecule, an elementary particle instead of an atom, a quark instead of an elementary particle. However, since quarks do not consist of smaller parts, it was originally believed that the computation speed of quark computing is the best we can do.

However, with millicharged particles, we have an understanding that in the close vicinity of each elementary particle, there is a large number of compenstaing millicharged particles. If we can use these compensating particle for computations, this will allow us to make the size of the computational unit even smaller.

Acknowledgments

This work was supported by the AT&T Fellowship in Information Technology, by the Institute for Risk and Reliability, Leibniz Universitaet Hannover, Germany, by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) Focus Program SPP 100+ 2388, Grant Nr. 501624329, by the European Union under the project ROBOPROX (No. CZ.02.01.01/00/22 008/0004590), by the Center of Excellence in Econometrics, Faculty of Economics, Chiang Mai University, Thailand, by the Ho Chi Minh City University of Banking, Vietnam, and by Thang Long University, Hanoi, Vietnam.

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