

On the Track of Modern Physics

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Introduction

„Physics” - what a terrible word! Trolleys, vectors, Newton’s forces that nobody understands.

On the other hand, a funny Albert Einstein, who invented something very interesting - that mass is energy. But can mass exist without energy or energy without mass? This is just confusing. Then, people say it was actually Einstein's wife who wrote everything - to her he donated his Nobel prize. Really?

“Modern” is more difficult to define: Newton is “ancient” and Einstein “modern”? We define “modern” as that which is still open in Physics - finding new applications, for example in Archaeology or Agriculture, and new, surprising conclusions.

The “Track” deals with different sectors, like Atomic, Nuclear, or Astrophysics. But attempts to catalogue Science are hopeless. In this sense, the “honeycomb” we show is an oversimplification: Atomic Physics is close to X-ray Physics but also to Solid-State, Nuclear and so on. We call our exhibition a “Track”, i.e., something which has a beginning, some indications, some ramifications (sometimes dead ends) but nobody knows where (if anywhere) it ends.

Our main point here is that Physics is frequently so difficult that it gets presented in half-ridiculous ways. With obvious harm to Physics.

We propose a new way of presenting Physics, not as *knowledge* but as a *methodology*. So we do not present results by Röntgen, but rather his errors. We treat Physics as a *process*, not as a closed system: the only way to avoid rewriting all textbooks from time to time.

We present the most modern *achievements*, but also *open questions*. We present *theory*, but also *practical applications*. Physics is not divided into rigid sectors but forms a circle –

different techniques are applied in unexpected fields. Finally, we show the *human factor* – discoveries cannot be separated from real people - scientists, with their everyday problems. Below we give three examples from 25 posters already prepared within the Project.

Albert and Mileva – a marriage of love

Albert, as was told by his two years younger sister Maja, learned to speak quite late. He used to „drawl” sentences, as if contemplating them. His mother Paulina taught him to play the cello, his uncle Jacob taught him algebra and an older friend, a student of medicine, used to lend him popular-science books. At the age of 15, he studied by himself differential calculus.

When Albert was one year old, his father’s company went bankrupt, and the family moved from Ulm to München. Bismarck’s school system, closed-minded teachers and studying as a duty, made school into a nightmare. In Italy, where his father had moved just before Albert’s graduation, he revived.

His parents wanted him to study at the Polytechnic in Zurich – the best university outside Germany. Without *Abitur* he had to pass the admission exams. He failed in German and philosophy. Following the Rector’s advice, Albert stayed for one year in Switzerland, where he finally got his *Abitur*. But against his father’s will, Albert decided to become a scientist, not an engineer.

Once more Albert did not obey his father: when he fell in love with Mileva Maric, a student of mathematics from Serbia (under Austria at that time). In 1901 they had a daughter who (probably) died. Mileva failed her graduation exams and stayed without a job. The university research position, promised to him, went to someone else: Albert was also left **without a job**. Only after his father death, Albert married Mileva. In 1904 their first son was born. Albert’s friend found him a job in Bern as a patent examiner. In a short time, till 1906, Albert published 6 papers.

In 1908 he became a „Privatdozent” at Bern University and a year later an associate professor at Zurich University. This position was first offered to his friend Friedrich Adler – a dedicated socialist who recognized that **Einstein was better**.

The marriage with Mileva was a **marriage of love**. Albert wrote to Mileva with tenderness „my little doll”, and about the relativity theory he wrote „our theory”. In the summer of 1914, shortly before the war, Mileva left Berlin, where Albert had moved, and went back with the children to Zurich. Albert, with a friend, published a pacifist „Manifest to Europeans” – which isolated him within the Berlin university staff.

Our main point here is that Einstein’s biography is the most favourite object of mythology within science and journalistic paraphrases. They usually are harmful both to Einstein’s memory and to an understanding of his achievements.

We say, that he was *perfectly* normal, with all the problems of a young person. He was even less fortunate than many of his colleagues, at least at the beginning of his scientific work. So not his achievements should appeal to young people, but his *faults*.

The so called human factor is decisive in scientific work. Without stable personal life and a fixed job, even Einstein would have discovered nothing.

Obviously, for a *detailed* biography of Einstein you should consult other texts. And for Einstein’s original papers just consult the internet version of the exhibition.

Atom, i.e. in-dividual

„Tria àtoma” shouts the ski-lift operator in Taigetos, in the snowy mountains of the Peloponesus, near Sparta, when the next wagon is approaching. Today, the word „a-tomos”, in Greek, has the same meaning as in Democritus’ times

Atoms for Democritus had two properties: size and shape.

1. Atoms connect to each other in different proportions (stoichiometry and structural formula?) and create different substances.
2. Atoms are in permanent motion and collide with each other (like in Boltzmann’s perfect gas model?), their motion determines their mass (the mass of a proton results not from the gluons’ rest mass but from their motion, thanks to Einstein’s $m=E/c^2$)
3. Atoms emit a fluid (photons?) which can be observed

Can we agree with Democritus now, in the XXI century?

The picture is Taiget mountain in December

How to count atoms? The best way is on your fingers. But you need a very small finger!

1. Atoms can be „counted” quite precisely by X-rays: they are diffracted from crystal planes, like light from a CD. The closer the atoms are, the more distant are the light spots on the screen.

2. There are others ways of counting atoms (i.e., by calculating Avogadro’s or Loschmidt’s number). For example from the sedimentation rate in a liquid (J. Perrin) or from Brownian motion (A. Einstein).

3. Today it is possible to count on „fingers”, leading them over a crystal surface. But the finger must be quite small and precise: the best is the sharp tip of a tungsten needle – when it touches an atom (or better: approaches it) the needle is attracted slightly.

We call it *Atomic Force Microscopy*.

„Dimensions” of atoms can be obtained in many ways but one may get very different answers

1. In gases, the atomic "dimension" is the distance, at which they start to push each other in a rather brutal way – their diameters are estimated with deviations from the perfect-gas equations, when it is impossible to compress the gas any further and it condenses. Like the dew in the morning.

2. In liquids, the dimensions of the particles influence the “neighbourhood” effects, like the viscosity. Huge molecules, like a polymer, never stop slipping.

3. In crystals, atomic diameters are defined as dimensions of elementary cells, visible by X-ray or electron-beam diffraction.

Atomic diameters could be also evaluated from the density – if we knew how many atoms were contained in a portion, i.e., in one mole of the substance. But we need to know advocate Avogadro’s number, which is also difficult

Our main point here is that the concept of atom is the best example of the evolution of ideas: from speculations to their negation, to new experimental indications, and back to speculations.

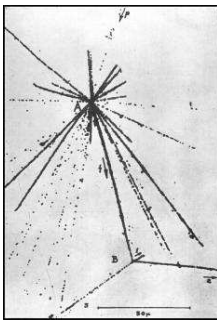
An atom, from the point of view of Physics is not an *a-tom*, i.e., an in-divisible. But just playing with words we get *in-dividual*, which is similar, but used rather for persons (in italiano *in-dividuo*, in Polish or Russian *o-soba*).

So, in order to explain the meaning of *atom*, we come back to the original Greek meaning. This playing with words shows how *Philosophy* can be useful for Physics. Furthermore, experimental proofs for the existence of atoms came quite recently: with Perrin's experiments and with Atomic Force Microscopy allowing us to scan atom by atom on the surface of solid bodies. The so called Avogadro's number was merely a hypothesis in Avogadro's times.

How can one find a quark?

You need a little luck and a huge accelerator – a ring of several kilometres diameter, consuming electricity like a medium-size city.

1, 2. The first pair – “up” and “down” are everywhere, being components of atomic nuclei.



3. The lighter of the second pair, “strange”, is a constituent of particles heavier than proton and neutron and was observed in cosmic radiation in the forties. These strange particles can be captured by atomic nuclei for a glimpse, before decaying. This picture shows a first noticed trace of a decaying hypernucleus in a photographic emulsion.

M. Danysz and J. Pniewski, *J. Phil. Mag.* **44** (1953), 348

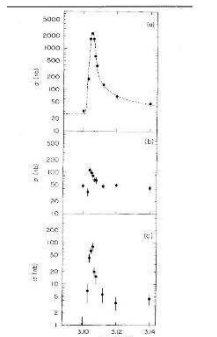


FIG. 1. Cross-section versus energy for (a) neutrino-hadron final states, (b) e^+e^- final states, and (c) $\mu^+\mu^-$, e^+e^- , and $\mu^+\mu^-$ final states. The curves in (a) in the upper part are of e^+ -neutrino resonances fitted with the Gell-Mann theory of the lepton and neutrino radiative processes. The cross-sections shown in (b) and (c) are calculated over the detector acceptance. The total hadron cross-section, (d), has been corrected for detection efficiency.

4. The “charm”, completing the second generation was the subject of twofold hunting: in Brookhaven a narrow peak was observed at 3.1 GeV for electron- positron pair production in $p + Be$ collisions, in Stanford on the other hand – a peak for hadron production in electron- positron annihilation; the papers were submitted with one day's difference, the $c\bar{c}$ meson bears a double name J/Ψ , and the Noble prize was shared by both groups.

There was also a third group, from Rome, who published a paper just after the two others. But they admitted to have adjusted their machine for the shot after a call from the USA. No Nobel prize for them...

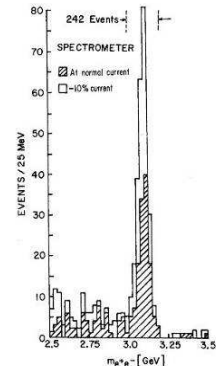
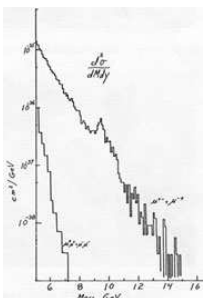


FIG. 2. Mass spectrum showing the existence of J/ψ . Results from two spectrometer settings are plotted showing that the peak is independent of spectrometer currents. The run at reduced current was taken two months later than the normal run.

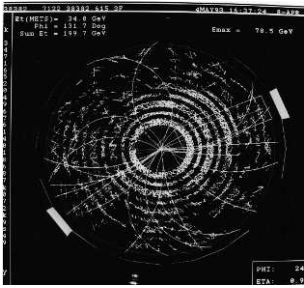
J.-E. Augustin *et al.*, *Phys. Rev. Lett.* **33**, 1406–1408 (1974) J.J. Aubert *et al.* *Phys. Rev. Lett.* **33**, 1404–1406 (1974)



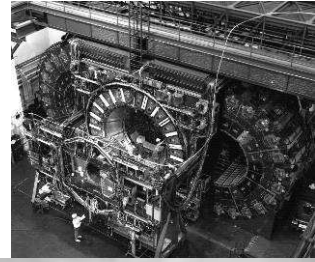
5. The third generation was first predicted theoretically by M. Kobayashi and T. Masakawa in 1974. The “bottom” quark, also called “beauty”, was observed in 1977 in FermiLab in the production of muons from proton scattering on Cu or Pt, as a faint “bump” ($Y - \text{Upsilon meson } b\bar{b}$) at 9.5 GeV mass.

Credits: Fermilab





6. The last, “top” is so heavy (175 GeV) that it becomes the father for generations of other particles – so called jets; its mass was predicted correctly by theory and was measured with the best accuracy in the whole quark zoo.
Credits: Fermilab



Bigger and bigger machines are needed to find tiny quarks!
So if you have no money, or you do not believe in new quarks, you can still find it in the bakery in Trento, Italy.

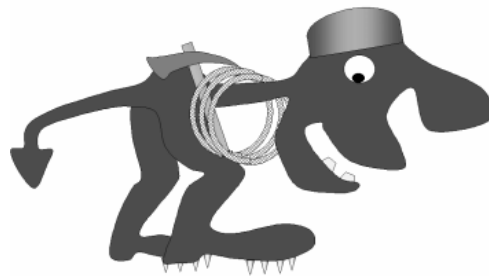


How can one show a quark? Do we know everything about quarks?

No! We do not even know the masses of the lightest quarks!
The best data for *up* and *down* quarks masses are:

$$1/2(m_u+m_d)=4.2 \text{ MeV}/c^2; 1.5 < m_u < 5 \text{ MeV}; 5 < m_d < 9 \text{ MeV}/c^2$$

Determination of masses is more precise for heavier quarks, for example the *strange* quark shown below $m_s=0.105 \pm 0.033 \text{ GeV}/c^2$ (negative charge)



or the *top* quark, shown here:
 $m_t=175 \text{ GeV}/c^2$ (positive charge)

Our main points here are:

- from a historical perspective some of the fierce competition between scientific groups, even if it brought a Nobel prize, appears simply ridiculous
- the masses of the lightest quarks are known only with 50% error bars
- the experiments on elementary particles are becoming so expensive that a serious critical discussion on research priorities must take place in the scientific community
- one should try to visualise the phenomena, exploring models beyond simple colourful balls, as usually used for quarks

- this visualisation should bring some new information, like the size of the quark here, corresponding to its mass (the mass is proportional to the fourth power of linear dimension here)
- we again play with words: “quark” was used by Gell-Mann, from a novel by James Joyce, who probably used a word he had heard in Germany, namely white cheese (ricotta in Italian): Quark

Project

The project “Physics is Fun”, financed by the EU “Science and Society” framework, aims to:

- de-mythologize Physics
- make it appealing and easy
- stimulate fantasy and imagination
- show interdisciplinarity and new applications
- inform policy makers on possible promising research priorities
- induce scientists to some criticism

You will find all the material from “Physics is Fun” project at: <http://modern.pap.edu.pl>

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