

The relation between energy and
mass in the works of Einstein,
Landau and Feynman

The talk at the Memorial Meeting
dedicated to the 100th birthday anniversary
of L.D.Landau,
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Personal gratitude

First of all I want to express my deep gratitude to Lev Davidovich Landau (Dau). He predetermined the direction of my worldline in many ways. First, through his influence on my professor and teacher Isaak Yakovlevich Pomeranchuk (Chuk). Second, through the Course of theoretical physics published by him and by Evgenii Mikhailovich Lifshitz. Third, through personal contacts.

Pomeranchuk advised me in 1950 to attend Landau's seminars on Thursdays at the Kapiza Institute of Physical Problems (IPP). In 1954 I became Pomeranchuk's graduate student at Thermo-Technical Laboratory, TTL, where Dau had a part-time position. (TTL was later renamed into Institute of Theoretical and Experimental Physics, ITEP). Now I was able to see Dau not only on Thursdays at IPP, but also on Wednesdays – the days of A .I. Alikhanov's seminar at ITEP.

Dau at ITEP

This was a remarkable experience!. During the seminar, which was mainly experimental, Dau was sitting in the first row together with Alikhanov and making sharp remarks. After the seminar he would move to the office number 9, just behind the lecture hall, to chat with theorists. Sitting in a deep armchair and stretching his long legs, Dau with virtuosity discussed questions posed to him by Chuk and his team: V.B. Berestetsky, A.D. Galanin, A.P. Rudik, V.V. Sudakov, B.L. Ioffe, I.Yu.Kobzarev, and myself.

The hottest subjects under discussion were the so-called “theta-tau puzzle” and “nullification of charge”. Theta and tau were the names of decays of kaons into two and three pions correspondingly. They started to look as decays of the same particle, which meant that parity P is violated. Davao considered violation of parity – of symmetry between left and right – in nature as aesthetically ugly. First he tried to deny the possibility of P violation, but finally gave up and put forward the idea of exact conservation of combined CP parity. A beautiful realization of CP symmetry was the idea of longitudinally polarized massless neutrinos and anti-neutrinos.

These ideas were accepted enthusiastically by physicists. Though later minor effects of CP violation in weak decays and tiny neutrino masses were discovered, still CP and longitudinal polarization are “the reference concepts” of modern fundamental physics. The importance of CP violation for the baryonic asymmetry of the Universe and hence for our existence was stressed in 1967 by Andrei Dmitrievich Sakharov. But the origin of this violation in cosmology is still unknown.

The “nullification of charge” turned out to be no less deep. The growth of electric charge of the electron with the increase of momentum transfer seemed to imply that any finite charge at the shortest distance would result in a zero observable charge at large distances. The solution of this paradox came later with the discovery of the asymptotic freedom in the non-Abelian gauge theories.

Unfortunately, a recurrent administrative reform prohibited scientists to combine jobs. Dau was offended and ceased his weekly visits to ITEP. Then came the tragic January 7 1961.

Teaching the theory of relativity

“Teoriya polya” by Landau and Lifshitz was the book from which most of us, Russian theoretical physicists, learned relativity. The mass in this book is expressed through energy and momentum by the relativistically invariant equation

$$E^2 - \mathbf{p}^2 c^2 = m^2 c^4 .$$

(If the speed of light c is used as the unit of velocity, then $E^2 - \mathbf{p}^2 = m^2$.) The book by Landau and Lifshitz served as a vaccination against the virus of relativistic mass, defined by the famous but misleading formula $E = mc^2$.

Only a few years ago did I realize that “Teoriya polya”, which appeared in 1941, was the first monograph on relativity in the world that did not use the concept of mass depending on velocity. And only a few months ago had I discovered that in none of his writings on mass and energy did Einstein use the equation $E^2 - \mathbf{p}^2 = m^2$. Though quite often he used the equation $E_0 = mc^2$, which defines the rest energy E_0 , he nevertheless insistently spoke about complete equivalence of mass and energy.

Listen to Einstein:

<http://www.aip.org/history/einstein/voice1.htm>

Einstein speaks:

“It follows from the Special Theory of Relativity that mass and energy are both but different manifestations of the same thing – a somewhat unfamiliar conception for the average man.

Furthermore the equation $E = mc^2$ in which energy is put equal to mass multiplied with the square of the velocity of light showed that very small amount of mass may be converted into a very large amount of energy and vice versa. The mass and energy were in fact equivalent according to the formula mentioned above. This was demonstrated by Cockcroft and Walton in 1932 experimentally.”

Einstein and Landau

In the winter 1928-29 Landau, who was at 21 years of age, met Einstein (at 50) in Berlin. According to Landau, they discussed quantum mechanics.

According to recollections of Rumer, Landau commented a seminar given by von Laue and Einstein asked: Was ist das?

Not much is known to me about their meeting(s)

The somewhat blurred views of Einstein concerning energy and mass seem to be at the heart of the century - long confusion which could be called “Does mass depend on velocity?” The famous book by Born, as well as dozens of other textbooks said “yes!”. This “yes” was dogmatized in hundreds of articles and books popularizing the relativity theory. Even Landau in a brochure “What is relativity?” coauthored with Rumer had chosen to join the popular bandwagon.

Landau and Feynman

Landau and Feynman never met.

In a sense Landau and Rumer were followed by Richard Feynman, Robert Leighton and Matthew Sands in the famous “Feynman Lectures on Physics”, though the velocity-independent mass is the cornerstone of the method of Feynman diagrams.

Last year I exchanged a few emails with M. Sands – the man who initiated “The Feynman Lectures”.

On January 12, 2007 he wrote:

“I agree with you that it would be preferable to reserve the symbol m as the invariant magnitude of the energy - momentum four-vector. I am surprised that Feynman did not take this view in Volume 1. I never discussed this with him at the time – Leighton was in charge of preparing that volume.”

On January 19, referring to Landau and Feynman, he characterized them as “two of the great teachers of physics in the last 50 years”.

Momentum versus velocity

It seems to me that the standard courses on relativity are too biased towards velocity, which at relativistic energies is “frozen” in the vicinity of c . Momentum is a “live” and hence a better variable to describe relativistic processes. Understanding experiments in terms of momentum is simpler than in terms of velocity. Starting the course on relativity with velocity reminds me lessons of swimming in a dry pool without water. It is much better to start with t, \mathbf{x} and E, \mathbf{p} and with relativistic version of Hamilton - Jacobi equation.

Spin

Another concept that deserves more attention in teaching relativity is spin. The spin of electromagnetic field and hence of photon is 1. That's why it is called vector field. The spin of the gravitational field is 2. This is a tensor field. Spins of photon and of graviton determine the most important features of electromagnetic and gravitational interactions. In a certain sense, these spins preceded the spin of the electron in the history of physics.

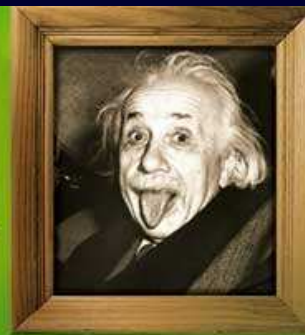
Conclusion

The introduction of only one mass – the Lorentz invariant mass m , as Landau and Lifshitz taught us, is the most adequate way of teaching relativity. No relativistic mass, no rest mass. Mass is equivalent not to energy E , but to the rest energy E_0 . The ad

of baby-food with $E_0 = mc^2$ was given to me by my grand-daughter Katya.

See the ad on the web: Агуша био w3.

детское питание
АГУША



НОВОЕ СЛОВО В ДЕТСКОМ ПИТАНИИ

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The ad looks more scientific than many of physics textbooks which advertise $E = mc^2$.