

# LETTERS ON WAVE MECHANICS

Schrödinger  
Planck • Einstein • Lorentz

*Edited by*

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for the Austrian Academy of Sciences

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8. Schrödinger to <sup>Max</sup>Planck  
(graduate advisor)

Zürich

4 July 1927

*year of  
Copenhagen  
interpretation*

My dear Professor,

.....  
May I talk a little physics yet? I should like so much to know how the quantum situation is judged in Berlin and especially by you yourself. Is what the matrix-physicists and q-number-physicists say true—that the wave equation describes only the behavior of a statistical ensemble, just like the so-called Fokker partial differential equation perhaps? I would willingly believe it since the interpretation is really much more convenient, **if I could only pacify my conscience and convince it that it is not frivolous to get off so easily in overcoming the difficulties.** I believe I am right that you yourself wrestled with the first and most basic assumption of discontinuity (i.e. precisely “the quantum theory”) in its day, wrestled a hard intellectual struggle with your whole soul, as the “second version”<sup>7</sup> which followed so long afterwards shows most clearly. I believe that one is obliged to take up this struggle anew with the same seriousness among today’s newly emerged points of view. I do not have the feeling that this is really happening on the part of those

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<sup>7</sup> M. Planck, *Verhandlungen der Deutschen Physikalischen Gesellschaft* 13 (1911), p. 136. It is assumed here, by way of trial, that only emission from the atom takes place in quanta, but that absorption occurs continuously, an idea that later had to be given up. See especially Planck’s *Scientific Autobiography* (New York: Philosophical Library, 1949) pp. 43-46.

who today already announce categorically: the discontinuous exchange of energy *must* be adhered to.

What seems most questionable to me in Born's probability interpretation is that when it is carried out in more detail (by its adherents) the most remarkable things come forth naturally: the probabilities of events that a naive interpretation would consider to be independent do not simply multiply when combined, but instead "the probability amplitudes interfere" in a completely mysterious way (namely, just like my wave amplitudes, of course). In a brand new article by Heisenberg even my much smiled at wave packets are said to have finally found their suitable interpretation as "probability packets". The first is especially comical. It can also be expressed this way: the Born probability (more correctly its square root) is a two dimensional *vector*; its addition is to be carried out vectorially. The multiplication is still more complicated, I believe.

?

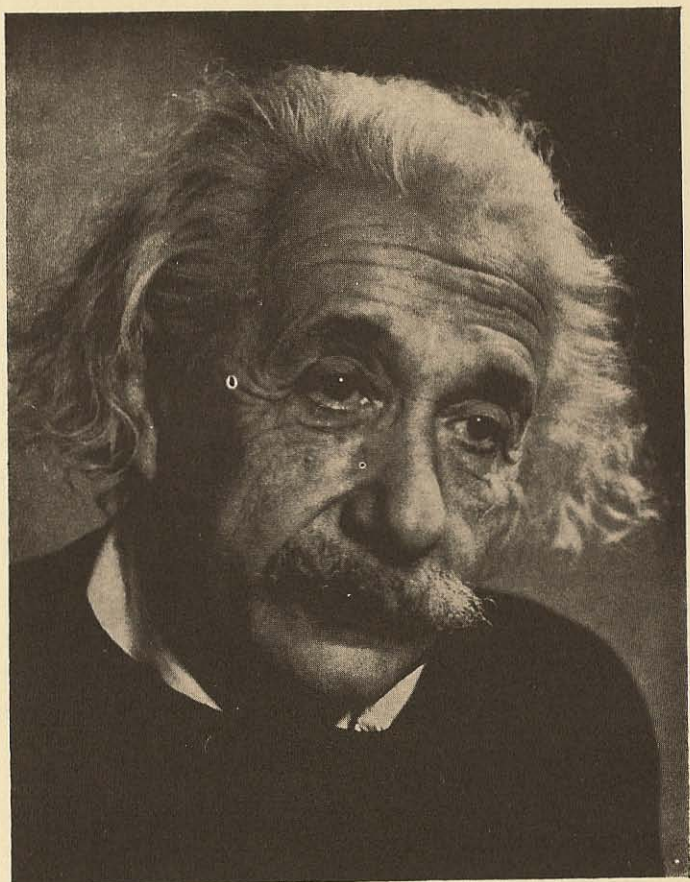
Well, as God wills; I keep quiet. That is, if one really *must*, I too will become accustomed to such things.

With kindest regards to your wife, Professor Planck, I remain

six years later  
he won the Nobel prize

Yours faithfully,  
E. Schrödinger





A. Einstein

Nobel winner  
in 1921

## 14. Einstein to Schrödinger

31 May 1928

Dear Schrödinger,

I think that you have hit the nail on the head. It is true that the evasion using the arbitrarily large domain of cyclic variables to limit the value of  $\Delta p$  is very ingenious.<sup>15</sup> But an uncertainty relation interpreted that way does not appear to be very illuminating. The thing was invented for free particles, and it fits only that case in a natural way. Your claim that the concepts  $p, q$  will have to be given up, if they can only claim such a "shaky" meaning, seems to me to be fully justified. The Heisenberg-Bohr<sup>16</sup> tranquilizing philosophy—or religion? —is so delicately contrived that, for the time being, it provides a gentle pillow for the true believer from which he cannot very easily be aroused. So let him lie there.

But this religion has so damned little effect on me that, in spite of everything, I say

not:  $E$  and  $v$

but rather:  $E$  or  $v$ ;

and indeed: not  $v$ , but rather  $E$  (it is ultimately real). But I cannot make head or tail of it mathematically. My brain is also too worn out by this time. If you would give me the

<sup>15</sup> See footnote 14 in the previous letter.

<sup>16</sup> See Bohr's account of his discussions with Einstein in Bohr's book *Atomic Physics and Human Knowledge* (New York: John Wiley and Sons, Inc., 1958), p. 32.

pleasure of a visit from you again sometime it would be good of you and very fine for me.

Best regards from

A. Einstein



*They both left Nazi Germany in 1933*

## 15. Schrödinger to Einstein

7, Sentier des Lapins  
LaPanne, Belgium  
19 July 1939

Dear Einstein,

. . . . .  
A few months ago a Dutch newspaper carried a report which sounded comparatively intelligent that you have discovered something important about the connection between gravitation and matter waves. I would be terribly interested in that because I have really believed for a long time that the  $\Psi$ -waves are to be identified with waves representing disturbances of the gravitational potential; not, of course, with those you studied first, but rather with ones that transport real mass, i.e. a non-vanishing  $T_{ik}$ . That is, I believe that one has to introduce matter into the abstract general theory of relativity, which contains the  $T_{ik}$  only as "asylum ignorantiae" (to use your own expression), not as mass points or something like that, but rather, shall we say, as quantized gravitational waves. I have done a good many calculations on this point but have found out very little, except that § 13.7 of Eddington's book "Protons and Electrons", which had fascinated me very much, is false. But it is unfortunately not very hard to find major errors in this ingenious book.

It's a shame that I had to fill so much of this letter with uninteresting personal things about myself, but it is really so terribly hard to write, (I mean about such things as those just above).

If this letter reaches you on your sailboat I wish you much rest and enjoyment there. I am wonderfully well off here on the charming Belgian shore with these delightful people, happy as children. If one could only be somewhat more light-hearted and could think less about what is to become of oneself. Vacations are fine, but a vacation for which one cannot perceive a definite end is a peculiar thing.

Best regards from

Yours sincerely,

E. Schrödinger