# Heaviside predicted Cherenkov radiation

Bruce Hunt's article about Oliver Heaviside (PHYSICS TODAY, November 2012, page 48) is interesting, useful, and instructive. An additional important detail is Heaviside's remarkable prediction of Cherenkov radiation.[1]

Flow around an obstacle with speed greater than the characteristic phase velocity of the perturbations results in a bow shock in front of the obstacle. That wave phenomenon can be explained by Huygens's principle. It arises in front of a bullet, a supersonic jet, or a moving boat. A hydrodynamical Mach cone may be observed even in a bath when you move a finger along the water surface faster than the phase velocity of surface waves.

The effect should also arise from a charged particle moving uniformly with velocity greater than the speed of light in the medium. Such an electromagnetic Mach cone was observed in 1934 by Pavel Cherenkov, who, along with Igor Tamm and Ilya Frank, was awarded the 1958 Nobel Prize in Physics for the discovery and its explanation. But the original idea of this effect belongs to Heaviside. Frank acknowledged Heaviside's priority in his detailed history of the discovery.[2]

In our opinion, Oliver Heaviside's immense contributions to science are still underestimated, and he has yet to receive the level of recognition he highly deserves.

## References

1. O. Heaviside, *Philos. Mag.* **27**(167), 324 (1889).
2. I. M. Frank, *Sov. Phys. Usp.* **27**, 385 (1984).

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# Time-reversal asymmetry and state-vector collapse

A sentence in the Search and Discovery story "Time-reversal asymmetry in particle physics has finally been clearly seen" (PHYSICS TODAY, November 2012, page 16) has me somewhat puzzled. Bertram Schwarzschild writes, "If the first decay of a daughter reveals it to have been in a specific flavor or *CP* eigenstate, her still undecayed sister must—at that instant—be in the opposite state." What is implicit in this sentence is that state-vector collapse takes place at the decay of the first B meson, so that the second meson is instantaneously projected onto the opposite state.

I have two objections to this sentence. First, it is not relativistically invariant: Because the two events—decay of the first meson and "transformation" of the second—have spacelike separation, their time ordering is not defined. Second, the decay is governed by a relativistic version of the Schrödinger equation, which is reversible, whereas state-vector collapse is, by nature, irreversible.

It is instructive to make a comparison with the analysis of a Bell-type experiment, in which a two-particle observable is measured via two detectors that are far apart, with each measuring the spin of one of the two particles. The quantum mechanical result is given by applying Born's rule to the two-particle observable.

The two experimentalists, Alice and Bob, then compare their results by exchanging them at a speed less than that of light, and they notice the results are correlated, in conformity with the theoretical predictions of nonlocal correlations. The same theoretical results may be derived from state-vector collapse: When Alice measures the first spin, Bob's spin is projected instantaneously onto a well-defined polarization state; correlations may be easily computed and are, of course, in agreement with those derived from Born's rule.

State-vector collapse is strictly equivalent to Born's rule in a nonrelativistic context, but I think it is safer to use Born's rule when special relativity comes into play. Indeed, to the best of my knowledge, there is no satisfactory relativistic generalization of state-vector collapse, which is understandable since simultaneity is not defined for two spacelike separated events. Therefore, a full justification of the argument used in the PHYSICS TODAY report should begin with state-vector collapse taking place in a well-defined reference frame at the instant when the decay products of the B mesons reach the detectors. Then, from the correlations observed between the results of the detectors, it should be possible to reconstruct the decays and show that they can be interpreted as an effective state-vector collapse.

Such an analysis would likely vindicate that of the BaBar experiment, but as the use of Einstein-Podolsky-Rosen correlations goes far beyond the usual one, it should be fully justified.

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# Geoengineering carries unknown consequences

I read with interest David Kramer's piece on geoengineering (PHYSICS TODAY, February 2013, page 17). I must say, I am more alarmed by what the geoengineers in his report are proposing than by the climate changes that are taking place. I believe geoengineers are removed from scientific reality. They ignore the fact that the climate system and its components—clouds, hurricanes, and so forth—are highly nonlinear and thus very sensitive to the initial conditions and to changes in the parameters. Nevertheless, one could study the system's response in a probabilistic way when certain parameters are changed or when we introduce fluctuations, if the relationships among all the components are known exactly.

And here lies the whole problem with geoengineering. The formulation of the climate system and its components is only approximately known. More than 30 climate models are floating around in the climate community, and their predictions about general dynamics simply don't agree with each other. In a recent publication,[1] we considered 98 control and forced climate simulations from 23 climate models and examined their similarity in four different fields (upper-level flow, sea-level pressure, surface air temperature, and precipitation). We found that except for the upper-level flow, the agreement between the models is not good. Moreover, none of the models compares well with actual observations.

One person in the PHYSICS TODAY story said that geoengineering may result in changes in various weather patterns, but nobody knows what the changes are going to be and how they will affect the climate system. If the warming in the Arctic is a big event to mitigate, then it will require a significant "geoengineering" effort. To me, that means significant changes will occur elsewhere. Who can say whether those changes will be less serious than those taking place now? How can geoengineers talk about modifying clouds and albedo when clouds are represented in the climate models as mostly linear parameterizations?

Kramer's report did not mention hurricanes, but geoengineers also propose to dissipate them. Hurricanes are unique in the climate system because they represent major self-organization. As physicists well know, self-organization occurs in dissipative systems in which energy is not conserved but instead is exchanged with the environment. Hurricanes involve huge amounts of energy. Scientists have little idea how the atmosphere and the ocean will be affected if that energy is not allowed to be exchanged.

I would not have a problem with geoengineering if the physics and dynamics of the climate system were well known. Climate scientists have a good idea of the large-scale flow of ocean currents, but detailed measurements are not available. They know the basic physics of cloud formation and its thermodynamics but do not fully understand detailed cloud microphysics or the complex connections between climate and ecosystems. And with complex nonlinear systems, details are important. So we need to make an effort to improve our understanding of our climate system and its components before we try to operate on it. We can engineer a car or a plane because we know the underlying physics of motion, combustion, and flight, and we understand the role of every component. Can geoengineers say the same about climate?

## Reference

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Letters and commentary are encouraged and should be sent by email to ptletters@aip.org (using your surname as the Subject line), or by standard mail to Letters, PHYSICS TODAY, American Center for Physics, One Physics Ellipse, College Park, MD 20740-3842. Please include your name, work affiliation, mailing address, email address, and daytime phone number on your letter and attachments. You can also contact us online at http://contact.physicstoday.org. We reserve the right to edit submissions.

# Water weight figures in jetpack dynamics

Authors Matthew Vonk and Peter Bohacek, in their Quick Study on jetpacks (PHYSICS TODAY, January 2013, page 54), include in their weight calculations the water in the suspended feed hose. Since the mass of the water is supported by the pressure of the watercraft's output jet, it ought not to be included. One can easily visualize this by imagining the hose and water standing upright on their own: The hose will fall from its own weight, while the water column will continue to rise upward, thanks to the system pressure behind it.

The skin friction between the upwardly flowing water and the interior surface of the hose further diminishes the effective weight of the suspended hose, although that factor will contribute little to the net force acting downward.

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■ **Vonk and Bohacek reply:** We'd like to clarify two points that weren't explicit in our Quick Study. First, between the watercraft and the jetpack, the extra hose simply floats near the river's surface. Because the floating portion of the hose cannot support any additional weight without sinking, the full weight of the water above the river's surface must be supported from above. Second, the initial velocity of the water from the personal watercraft is horizontal. Thus the water must be accelerated upward by the upward-curving hose, which exerts an additional downward force on the jetpack. In the end, the downward force exerted by the hose water on the jetpack is greater than, not less than, the simplified calculation in the Quick Study.

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