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Staggering domino-like blast front motion in a one-dimensional cold gas

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The relationship between the macroscopic dynamics of matter, viewed as a continuous medium, and that of its microscopic corpuscular constituents is a paramount challenge in physics. Its prominent 20th-century formulation is Hilbert's sixth problem, which specifically calls for 'developing mathematically the limiting processes… which lead from the atomistic view to the laws of motion of continua' [1]. This applies to the transport of energy in a cold gas following an explosion – an instant injection of energy at a certain point. In this talk, we show that a typical and relatively simple model of this phenomenon may exhibit surprisingly counterintuitive behavior.

We study the model in which point particles with masses $m, \mu, m, \mu, \ldots,$ $(m \geq \mu)$ are distributed on the positive half-line $\mathbb{R}_+$. Their dynamics are initiated by giving a positive velocity to the leftmost particle; in its course, the particles undergo elastic collisions. For this model with $m/\mu = 2$, it has previously been established that the dynamics that start from random initial positions are consistent with predictions based on Euler's hydrodynamic equation [2]. In particular, they have the following properties: (i) the position of the rightmost particle (shock front) evolves as t^δ with $\delta < 1$; (ii) recoiled particles behind the front enter the negative half-axis, $x \leq 0$, and form a splatter; (iii) particles in the splatter move ballistically and eventually take over the total energy of the system.

We present numerical and analytical results for the dynamics of this model with nonrandom (typically equidistant) initial positions and various values of m/μ [3,4]. For $m/\mu = 2$ and equidistant initial positions, our results qualitatively agree with those just mentioned. At the same time, we found an infinite family of numbers $\{\mathcal{M}_k\}$ such that, for $m/\mu = \mathcal{M}_k$, the hydrodynamic behavior mentioned changes drastically to the following. At each moment, only a single triplet m, μ, m is in motion, whereas all other particles are at rest. In the moving triplet, two heavy particles move to the right, while the lighter particle oscillates between them, transferring energy and momentum to the right. As a result, the shock front moves ballistically with an average velocity equal to the initial one. We refer to this regime - where motion is transferred sequentially from one triplet to the next - as 'staggering domino-like behavior.' This observation points to a breakdown of hydrodynamics and indicates non-ergodicity, as the system retains a dependence on the initial state at all times. We support our explicit calculations with molecular dynamics simulations. Such a staggering domino-like picture is obtained as an exact solution, which yields, in particular, explicit formulas for $\mathcal{M}_k$ and the particle velocities and positions. Its details and importance in a wider context are also discussed.

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[4]. T. Holovatch, Yu. Kozitsky, K. Pilorz, Yu. Holovatch. Phys. Rev. E, submitted, (2026), arXiv:2605.16125.

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