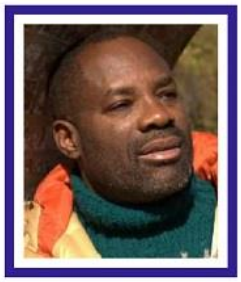

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Quest for Internet

In this second installment of our weekly Monday series at emeagwali.com, we focus on his discovery of how to accurately solve the most important problem in mathematical physics. The discovery was made in 1982 but made the news in 1989 as part of a larger discovery.

Regards,

emeagwali.com

Solve the Problem, Not the Formula!

By Philip Emeagwali

Edited and updated from a private seminar delivered by Philip Emeagwali in Washington D.C. (near the White House) in December 1982 and at a gathering of the Who's Who in the World of Mathematics in July 1991 also in Washington. Some lecture videos are posted at emeagwali.com and youtube.com/emeagwali

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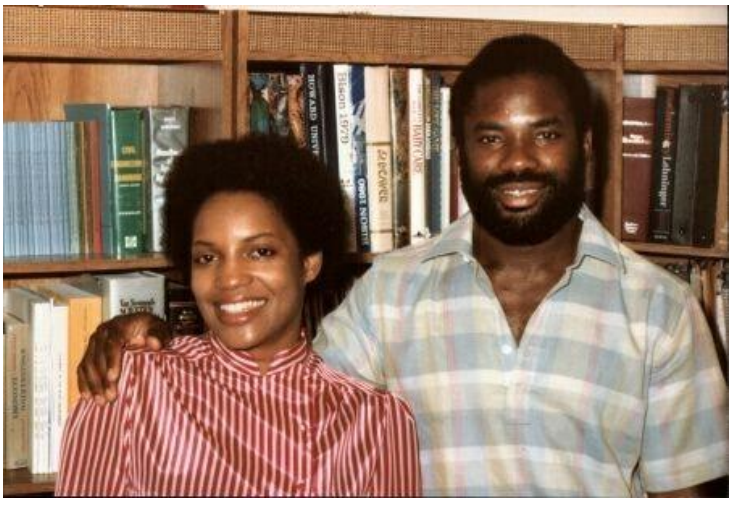

"Your **F**orce *is not equal to* my **ma**. When **F≠ma**, then the contract between mathematics and physics is violated," I said as the guest speaker at the International Congress on Industrial and Applied Mathematics, held on July 8, 1991, in Washington, D.C. This was the World Cup of Mathematics—held once every four years.

I was asked to talk about how the nine partial differential equations I had invented—in the most advanced form of calculus—could be used to recover more oil. During my presentation, I told my audience that the equations in all textbooks on porous media flow were not equating to what is inside a petroleum reservoir and, for that reason, the algorithms used by the industry would not accurately simulate the reservoir. While they pondered my bold assertion, I continued:

"A mathematical model is an approximation with a *little* falsification. However, summing three forces, where we should sum four, is a *great* falsification. In modeling petroleum reservoirs, the fourth force—inertia—is the proverbial uncle no other family member wants to talk about."

I insisted that since my model is a mathematical representation of the reservoir—inside two-to-power sixteen, 65,536, computers interconnected by sixteen times two-to-power sixteen, or 1,048,576, bi-directional communication wires as a superinternet—it should account for all the four forces in it just like a clay model of a dog, should have four legs, not three.

How ironic that I, a then 36-year-old superinternet scientist, was explaining the simulation of petroleum reservoirs to mathematicians, physicists, and geologists. With my discovery, I had essentially entered petroleum engineering through the back door in my efforts to apply the Second Law of Motion farther, wider, deeper, and higher, along the directions of physics, mathematics, two-to-power sixteen, or 65,536, computers that defined a supercomputer, and their sixteen times two-to-power sixteen, or 1,048,576, interconnections that outlined a superinternet that is metaphorically shaped as a cube in the sixteenth dimension, with each direction yielding a different vision of the Second Law of Motion. My goal was to re-discover the Second Law of Motion and all of its derivative equations and algorithms, so I began with a blank sheet of paper.

In physics, "to discover" is to create new knowledge that pertains to matter and energy and their interactions. Similarly, in geophysics, "to discover oil" means to extract up to 50% additional oil by secondary recovery, which is important because only 10% can be extracted by primary recovery (i.e., drilling a hole in an oilfield). As background, note that secondary recovery requires injecting water into a reservoir to drive the oil to the production wells. It thus required increasing the inertial force that we ignored. The first step in secondary recovery, therefore, is to use the Second Law of Motion to accurately simulate the flow of oil, water, and gas within the

reservoir. The software used to do this simulation is called petroleum reservoir simulator.

African Renaissance without Innovation is Void

The new "Negritude" goes beyond culture and tradition to encompass creativity and innovation. As Nnamdi Azikiwe said; "Originality is the essence of true scholarship. Creativity is the soul of the true scholar." Between ~~Africa and America~~, the 54 states in Africa and the United States of America, technological innovation is the elephant in the room. We see the absense of innovation in Africa — the birth place of science and technology. But like the elephant in the room, no one wants to talk about it. For forty years, I often asked: "Why is it that Nigeria pays a 40 percent tax to an American oil company? I learned its a no-go subject.

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So what did I discover in physics? How will it increase the oil recovered?

I discovered that geophysicists had misapplied the Second Law of Motion, and consequently had *inaccurately* simulated petroleum reservoirs. The law, discovered 330 years ago, is the most important discovery in physics; however, it was wrongly applied in oil recovery.

As is well known, the Second Law of Motion defines the relationship between the mass (m), acceleration (a), and applied force (F) of the oil, water, and gas inside a reservoir ($F = ma$). As is not well known until I discovered it was that in petroleum reservoir simulators, F *is not equal to* ma!

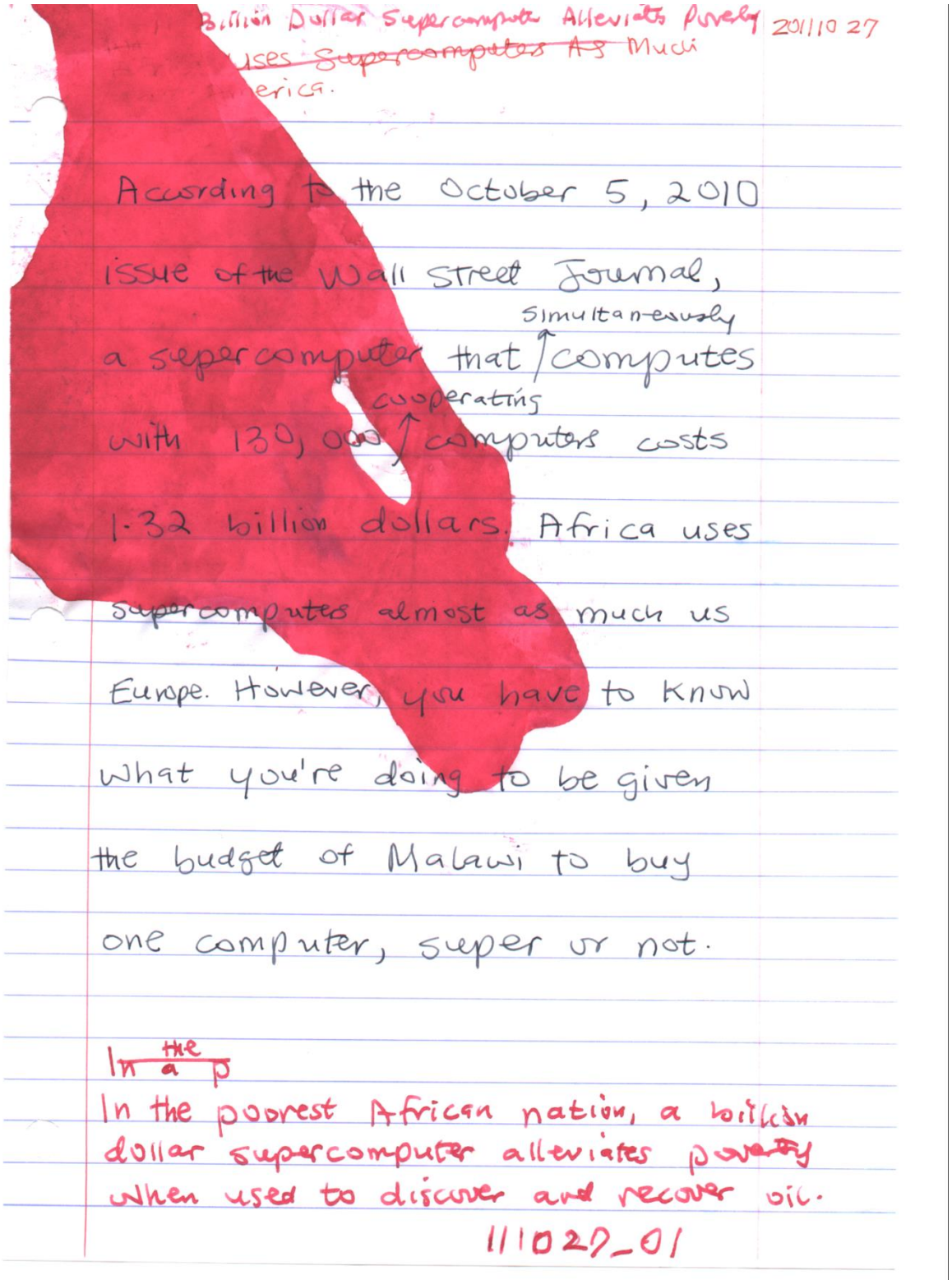
In my supercomputer calculations, I realized that only *some* of the forces were summed. I pointed out that we should sum *all* the forces acting on the oil, water, and gas, and equate them to their mass times acceleration. With this insight in mind, I *de facto* discovered that all petroleum reservoir simulators are less accurate when they violate the Second Law of Motion. When a simulator's force *is not equal to* the reservoir's mass times acceleration, the accuracy of the reservoir simulator is reduced as is the oil recovered.

I discovered that Exxon, Mobil, and Shell summed only three forces within their simulators—namely pressure, viscosity, and gravity. Seeing that a fourth force, inertia, should also be summed, I noted that using the sum of only three forces, **F** (the applied force in the simulator) will *not be equal* to the **ma** in the reservoir because the reservoir contains four forces. Based on my findings, I told the oil companies:

"Your force is *not equal to* your reservoir's mass times acceleration, **F≠ma**. In my view, $F = ma$ is a *well-known* formula that is *not known well* by those who need to know it the most."

An equation is a relation between the left part and the right part of the equality sign. We have two equations: one inside the supercomputer and the other inside the reservoir. The left part in the supercomputer is not equal to the right part in the reservoir.

The physicist who simulates petroleum reservoirs cannot claim to fully understand the Second Law of Motion, or $F = ma$, which he/she learned in high school. He/she can only make such claim after correctly summing all four forces within a reservoir and applying that knowledge to recover more oil.



As an superinternet scientist, I am the outsider to physics who saw the inertial force that was previously unseen in any petroleum reservoir simulator. My invention was to make force equal to mass times acceleration in simulators and thus to

rediscover the Second Law of Motion within simulators.

My discovery occurred while I was solving one of the 20 Grand Challenge problems of supercomputing on two-to-power sixteen, or 65,536, computers that were interconnected by sixteen times two-to-power sixteen, or 1,048,576, bi-directional communication wires as a superinternet (a term that I coined). It occurred because I was aware that physics informs algebra, just as algebra informs calculus. I understood that calculus informs algorithm, just as algorithm informs each computer. And I knew that each computer uses its superinternet connection to inform its sixteen nearest-neighboring computers.

In what ways is this discovery game changing?

When the inertial force is not summed, the derivative equations—at the algebra, calculus, and algorithm levels—are not informed regarding the missing inertial force. Therefore, all the 65,536 computers will be misinformed that F≠ma**.** This violation of the Second Law of Motion will cripple the reservoir simulator because each of its billions upon billions of algebraic equations will be derived from the unbalanced $F = ma$ and will also be unbalanced.

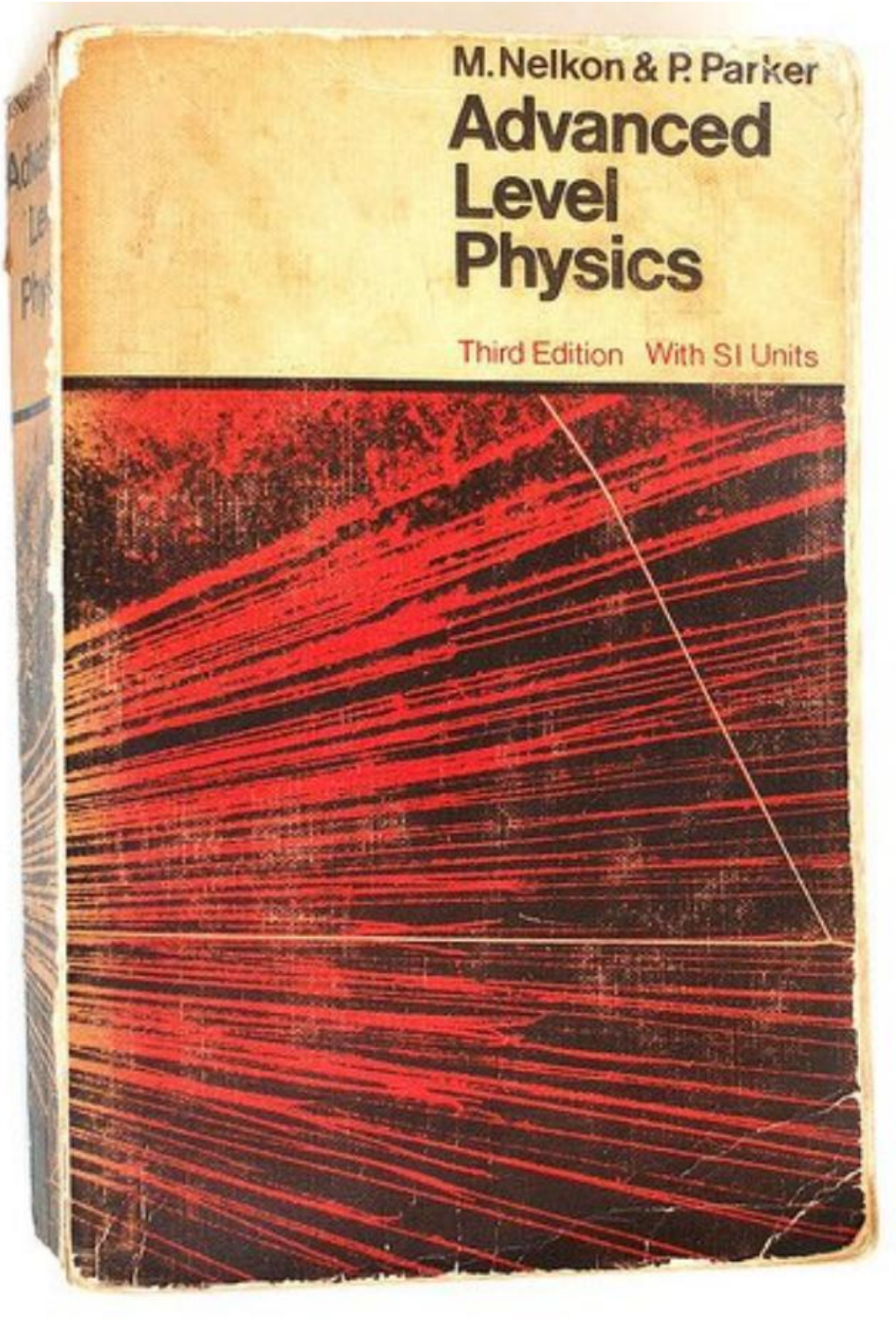
For the same reason, the iconic equation of geology and engineering—the 160-year-old Darcy's formula—is unbalanced. I discovered that Darcy's equation only summed *some* of the forces. I corrected it by summing *all* the forces. In essence, I re-discovered Darcy's formula.

Removing the inertial force *de facto* reduces the most important equation in the history of science in its most important application—the recovery of oil—to an equation without an equal (=) sign. I think of the three forces in the reservoir simulator used by Exxon-Mobil to recover oil as a four-chapter book that is missing one chapter. Or like a three-legged dog. That illustrates my thinking when I put the missing chapter—inertia—back into the story of oil recovery.

As for me, I am well known, but not known well. What was not known well was that I anchored my 3.1 billion calculations per second, which made the news in 1989, to the laws of physics. I programmed my supercomputer as a superinternet with the Second Law of Motion as my north star. When mathematicians lose their way, the laws of physics should serve as signs, each a compass pointing them back to the correct path. *In the end, the forces in our physical world must correspond to those on our storyboard, blackboard, and motherboard.*

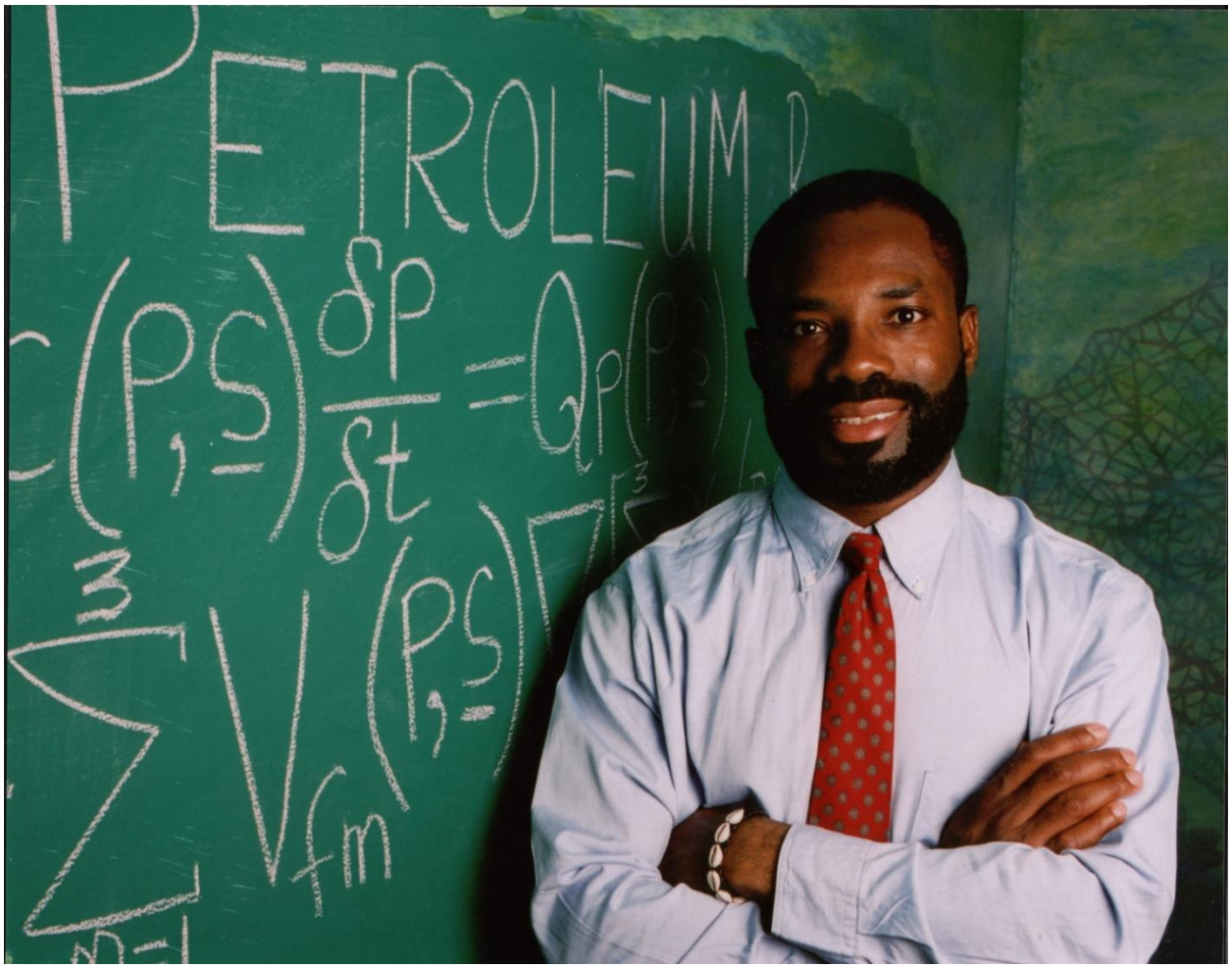
I exhorted mathematical physicists: "Please, solve the problem, not the formula!"

I



”Advanced Level Physics” by Michael Nelkon and Philip Parker was first published in 1958. I used the 1970 edition of this book to self-teach myself during after school hours at Sacred Heart Primary School in Ibusa (Nigeria) in 1972. The mathematics I created came from the Second Law of Motion described in high school physics textbooks such as the text above.

This is the publicity photo for a lecture I gave on July 8, 1991 at ICIAM '91, which is the World Cup of Mathematics. I told the field's foremost experts that my new mathematics came from inside a petroleum reservoir. [Philip Emeagwali, 1990]



Philip Emeagwali writes on the board the actual equations used by Exxon (now Exxon Mobil) to simulate the flow of oil, water, and gas inside its reservoirs. He discovered that their equations did not reflect reality and corrected their error. [emeagwali.com]