THE QUARK

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The Origins of Maglev Trains

By Dreshta Boghra

In 1902 and 1907, German engineer Alfred Zehden submitted the first two patents for a train propelled by a linear electric motor. In 1905, he was awarded a U.S. patent for the linear electric motor. In 1908, Tom l. Johnson, the mayor of Cleveland, filed a patent for a "high-speed railway" using magnetic levitation (maglev). Between 1937 and 1941, Hermann Kemper was awarded a series of German patents for linear electric motor propelled maglev trains.

Motors

The most commonly used type of electric motor, the rotary motor, uses one solenoid to induce a magnetic field. The direction of input for the current will always remain the same and the solenoid will rotate. When the current flows in the opposite direction, the magnetic poles will flip. Since the solenoid rotates, and the input for the current stays the same, the solenoid will "feel" the current in the opposite direction and the magnetic poles will flip orientation. The outside of the solenoid will have two static magnetic poles. The change in the polarities on the solenoid will push and pull from the static poles in accordance with how poles repel and opposite poles attract, thus resulting in a circular motion. On the contrary, magnetic levitation or "maglev" trains use linear electric motors which are non-mechanical motors. Linear motors require three solenoids and all three will switch polarities. Because AC currents go back and forth, the three solenoids will flip polarities. As one solenoid turns its polarity North, the next turns South, and the third turns neutral. There is a static magnetic track of alternating poles for the linear motor to travel on. The three solenoids will push and pull on the magnets on the track to move forward. Linear electric motors contributed greatly to the development of today's maglev trains. Currently, there are two types of maglev trains: those

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About The Quark

The Quark is a monthly newsletter produced by the Public Relations Committee of the Texas Tech chapter of the Society of Physics Students (SPS). Our goal is to help new students become more familiar with the Physics Department and provide returning students more insight on aspects of the department they might not have been aware about.

If you have any questions about The Quark or SPS, you can email our Public Relations Officer George Collier at george.collier@ttu.edu .

using Electromagnetic Suspension (EMS) and those using Electrodynamic Suspension (EDS) technology.

EMS and EDS Trains

EMS Trains

Transrapid 09 maglev train.

EMS trains utilize magnetic attraction to levitate. The trains' undercarriage contains magnets that wrap around the track. There are also a set of magnets on the bottom side of the guideway with opposite polarities from the magnets on the track. The attracting force must be strong enough to slightly overcome the weight of the train (the force of gravity) so that there is 1.3 centimeters of space between the train and the guideway and 8-10 cm between the inside of the bottom of the train and the bottom of the track. EMS trains can maintain levitation at zero velocity as well. EMS trains use linear motors for propulsion with static alternating magnets on the guideway and the motor is placed on the train. EMS trains were mostly researched in Germany. Germany's Transrapid International (TRI), a joint venture by Siemens AG and ThyssenKrupp, has been studying and exploring electromagnetic levitation for commercial use since 1969. They first built an EMS-based vehicle in 1969 and continued research, releasing eight more generations, the last two of which were implemented in Shanghai in January of 2001.

EDS Trains

In contrast, EDS trains utilize magnetic repulsion to oppose Earth's gravitational force. To do so, they make use of superconductors. Superconductors are conductors of electricity that carry absolutely no resistance. If you leave a current in a superconductor and come back to check years later, the amount of energy flowing would be the same. Superconductors are also perfect diamagnets because they completely repel magnetic fields. They do so because all of the electrons are paired. For a substance to become a superconductor, the material needs to be cooled to a very low temperature called the critical temperature. This temperature varies for each substance but is usually under 15 Kelvin. Cooling the material, most commonly with liquid nitrogen, removes thermal energy which allows the electrons to flow easily through the protons and become a superconductor. Because protons and electrons are oppositely charged and attract, protons will compress around the electron. The attracting force between the two eventually creates a larger net positive charge. Another electron will be attracted to the disturbance and move toward it; however, since there is already an electron in the disturbance, the two electrons will repel. This combination of attraction and repulsion locks the two electrons together, creating a Cooper pair. En masse, multiple electrons will pair together and flow as a large net. An interesting aspect of this phenomenon is that the pair will act like a boson. Electrons, neutrons, and protons are known as fermions. Fermions are physical particles that spin in half intervals. Bosons are particles that carry force and they have full integer spins. Thus, when two half integer spinning electrons form a pair, they can act as a full integer spinning boson. So Cooper pairs that are actually fermions but act like bosons. Cooper pairs can easily be broken by thermal energy which is why superconductors need to be cooled. Though Cooper pairs are weak, superconductors are extremely strong and can hold up to 70,000 times their weight. They are often used to generate extremely strong magnetic fields. EDS maglev trains have the guideway wrapped around the train. The train has to overcome the force of gravity to levitate. The superconductors are charged with a DC current which creates a powerful magnetic field and is used for levitation and propulsion. Propulsion is similar to how linear motors run, except it is flipped. These superconductors are used for propulsion along with metal coils. These loops will be lined up next to each other on the guideway and a current is sent through these loops so magnetic fields are generated. The current runs so that opposite poles are next to each other for each loop. The magnetic field on the track is the one that flips polarities and does so in accordance with the placement of the superconductor. The superconductor will repel the loop a little behind it and attract to the loop in front of it. As it aligns with the attracting loop, the current will flip directions causing the poles to flip. Now the attracting force is the repelling force and the same process repeats. The faster the poles flip, the faster the train goes.

In 1959, James Powell and Gordon Danby, researchers in the Brookhaven National Laboratory, brought forth a concept for magnetic levitation. To levitate the train, they decided to put static magnets placed in loops, such as a figure-eight loop, on the guideway. Another magnet is placed on the vehicle that will attract toward the upper loop and repel the lower loop. It was patented in 1968-1969. This concept is now used in EDS trains. Unpowered twisted coils are needed to levitate the train. A current is sent into this figure-eight-shaped loop to create a magnetic field on the top loop that attracts the superconductor and the bottom loop repels the superconductor. The coil is twisted so the top and bottom loop and have flipped magnetic fields in the perspective of the superconductor. The current is sent through to create a magnetic field due to Faraday's law. Faraday's law dictates that a change in magnetic flux can induce an electrical current in a coil of wire. Thus, an electrical current is induced in the twisted coil because the propulsion of the train creates a change in magnetic flux on the twisted coils. Since the levitation relies on propulsion, EDS trains cannot levitate at zero speed. To solve this, engineers put wheels on the bottom for slow-speed operations. On the contrary to EMS trains, EDS trains are not able to levitate at zero speed because levitations come from the train running. Research on EDS trains began in 1962 by the Japanese National Railway. They developed their own superconducting maglev, the SCMaglev, soon after 1969 when Brookhaven National Laboratory in the U.S.A. patented technology on superconducting magnetic levitation. In 1972, the SCMaglev made its first success at the Railway Technical Research Institute.

Conclusion

There are currently six commercial maglev trains in operation, three in China, two in South Korea, and one in Japan. As of 2021, the fastest is located in China with 600 km/h. Located in Qingdao, Shandong Province, this train shortens the trip from South China's Shenzhen to Shanghai, which is normally ten hours long, to 2.5 hours. Because Maglev trains need a special track, they are costly to build. In addition, rare earth elements used to create superconductors can be expensive to get. However, maintenance of the Maglevs is up to 70 percent lower than conventional trains. Nevertheless, maglevs are quiet, frictionless, energy-efficient, very safe with low chances of derailment, and eco-friendly. Maglev technology can only improve from here. It is bound to replace not only trains but many other vehicles and revolutionize transportation.

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Quantum Static Electricity

By Darby Hanes

Everybody knows why you shock yourself- you build up a charge in your body (usually by friction) and then when you come close to the nearest conductor, you feel the jolt of electricity leaving your body and transferring to said conductor. Back in my hometown of Houston, I never ever shock myself. But here in Lubbock (especially over Thanksgiving) it happens so much, it makes me want to believe I'm a superhero. After a quick google search, I came to the sad conclusion that it's just because Houston is humid and Lubbock is dry. It eventually led me down a fascinating rabbit hole dealing with the chemistry of water vapor. Here's the rundown, and I'll get to the cool chemistry stuff later. The water vapor in the air serves as a conducting vessel for the electricity to leave your body. Since Lubbock is essentially a desert, it has such little humidity that the charge just kind of stays with you instead of dissipating into the atmosphere. Water is known as a conductor of electricity, but that is not the case for distilled or deionized water, because they contain little or no ions. Ions are solely responsible for the conduciveness of water, and (according to USGS) that if water has enough ions, it will become a better conductor than the human body. Hence, if someone was swimming in a salty enough pool and lightning struck the water, the current could completely ignore the person and spread only in the water (USGS).

But, humidity is essentially distilled water, so it shouldn't contain very many ions and should therefore be an exceptional insulator and I would be getting shocked just as much at home as in the dorm. However, I did a little more digging and water vapor isn't as simple as I thought. An article published by a derivative site of West Texas A&M University postulates that the atmosphere itself is conducting electricity "In order to create an electrical current, electrons must be ripped off of the air molecules so that they are free to move and form a current.". However, the article is focused on the phenomena of lightning, not small amounts of charge that you shock yourself with. Just like anything in nature, air is complex and random. "Air is not ohmic at all. This means that there is no linear relationship between the electrical voltage applied to air and the resulting electrical current that travels through it.". A study by Mr. Hugh R Carlon showed that there are high ion concentrations in and evaporated water, but he later refuted it in another paper. So in conclusion, the conduciveness of air is decided mostly by the randomness of nature. Some of it is likely air, some comes from random minerals in the water vapor in the air.

Professor Spotlight: Dr. Katherine Long

By George Collier

First off, Thanks for giving me your time today, would you mind introducing yourself?

I am a professor in TTU's math department, though my background is in astrophysics. I got my BS from the University of Maryland and my PhD from Princeton, both in astrophysics. Before joining the TTU math department in 2007, I worked in the computational math research group at Sandia National Labs.

I often teach the Math Methods in Physics course sequence, as well as various courses in differential equations, applied analysis, and numerical analysis.

How did you get interested in Mathematics?

I wanted to be an observational astronomer and build telescopes, and to do that they told me I needed to learn math. That was worrying, since math had been my worst and most detested subject before college (in school I did well only in shop class), but much to my surprise, in college, I liked math. Even more to my surprise, I was good at it. As an undergrad I did much better in my theory classes than in my labs and observing classes and fell in love with figuring out how to solve physics problems on computers. Therefore, in grad school I specialized in theoretical and computational astrophysics.

When did you realize that math was what you wanted to do?

When I decided to stop working in astronomy, I first thought I'd go into engineering, and I worked for an engineering R&D company for a few years. I then got an attractive offer for a faculty job in mechanical engineering, but in contemplating that offer I realized I didn't want to focus only on engineering any more than I'd wanted to focus only on astronomy. What did I want to be when I grew up? My wife was a grad student in applied math at that time, and I saw the variety of problems people in her department worked on. I realized that a place where I could have contact with all my scientific interests – physics, engineering, biology, and scientific computing -- was in applied math. We both joined the computational math group at Sandia, and about a decade after that we found our way to TTU.

You focus on applied mathematics, what are some of the practical applications that you or other applied mathematicians have worked on?

My work in astrophysics had mostly been on the dynamics of galaxies, which involves nonlinear dynamics and fluid mechanics. When I started working in engineering, I could apply that knowledge right away to aerodynamics and microelectromechanical devices. While at Sandia, I got to work on an enormous variety of problems, including radiation detection, shape optimization for microfluidic devices, and particle transport in nanopores. These days, I work on problems in ecological systems, biomedical engineering, micromagnetic materials, and astronomy.

Common themes in my projects going all the way back to grad school are (1) numerical solution of differential equations (sometimes ordinary, usually partial) and (2) connecting simulation to experimental or observational data.

Other applied mathematicians work on topics as diverse as finance, sociology, sports statistics, and of course physics, chemistry, biology, and engineering. Recently I saw an excellent colloquium talk on combining PDE simulation, reaction kinetics models, and machine learning to model the spread of misfolded proteins in the human brain, towards understand the progression of neurodegenerative diseases such as Alzheimer's. You can use math and physics anywhere.

So those are equations that can't be analytically solved?

That's right. The equations are usually nonlinear, and furthermore in engineering or biomedical problems the PDEs are usually set in complicated geometries like engines, wings, brains, or hearts rather than rectangles or spheres. The familiar methods from your differential equations or math methods courses won't work here, so we're forced to resort to numerical simulation. But the numerical methods are ultimately built on ideas you learn in those courses, such as calculus of variations, Fourier analysis, infinite series, and linear algebra.

What are some of the things that you are researching currently?

One project involves a class of numerical methods called implicit Runge-Kutta IRK methods; these are used for time integration of differential equations. These have some useful stability and invariance properties, but in the context of time-dependent PDEs they give us large systems of linear equations that are very difficult and expensive to solve. I've been collaborating with Dr. Victoria Howle at TTU, our former PhD students Drs. Md Masud Rana and Ashley Meek, and our current graduate students Aman Rani and Abubakarr Yillah on designing efficient methods for solving linear equations having the structures that appear in IRK methods. Applications are to micromagnetics, where the stability and invariance properties of IRK methods are vital, to fluid mechanics, and to ecological systems.

With TTU physics graduate student Andrew Hamilton, I'm adapting a method developed by TTU's Dr. Wei Guo to solve the collisionless Boltzmann equation (CBE) in stellar dynamics. Because this is set in a six-dimensional phase space, this problem has usually been solved by N-body simulation rather than directly attacking the CBE. Dr. Guo's work on sparse grid finite element methods makes it feasible to work directly with the CBE, which will let us use some efficient methods for connecting simulations to observations and modeling stellar populations.

Another project, with TTU's Dr. Lourdes Juan, Dr. Andrey Morozov from the University of Leicester, and former Math Methods students Jackson Kulik, Jacob Slocum, and Megan Cuevas, is to use path integration to predict behavior in a structurally sensitive dynamical system. Here's what that means: Usually when you model a system, any simple function that has generally the right form will work; the fine details don't matter; every physicist learns to approximate a cow by a sphere. Usually, it works. But we've found that sometimes, a nonlinear dynamical system can be very sensitive to the functional forms used in the model. Two functions that look nearly identical and fit experimental data equally well can produce qualitatively different behaviors in the dynamical system. This isn't chaos, where you have sensitivity to initial conditions; it's something different, called structural sensitivity, and can occur even in dynamical systems that aren't chaotic. In such cases, we can't predict the behavior of the system with a single choice of functional form, but we must sample over all feasible functions – a path integral, just like in Feynman's path integral formulation of quantum mechanics – with each path weighted by how well it fits the experimental data.

Finally, I've been working on medical applications of infrared thermography in collaboration with a private company, a medical researcher at UTSW, TTU's Drs. Victoria Howle and Leif Ellingson, graduate students Michael Clines and Fahad Mostafa, and undergraduate students Eric Murray and Chance Willis. The mathematical work involves PDE simulation as well as statistics and machine learning. PDE simulation is used both to model physiological heat transfer within tissues, but also to try to get accurate estimates of the rate of convective heat transfer from the surface of the eye.

Wow your research is honestly incredible.

It's diverse. People often ask me "what can you do with math and physics" and I reply: what can't you do? Take any problem in the natural sciences, and there will be a use for math and physics somewhere. Even outside the natural sciences, math and mathematical methods from physics still appear.

Is there anything exciting happening in your field currently?

Oh yeah. Two things I'll mention are: numerical methods that are designed to take advantage of properties (such as invariants) of the differential equations being modeled, and very rapidly improving methods for connecting simulation to observational data. The latter is related to machine learning, which is often overhyped but when used carefully and coupled to physical understanding can be very powerful.

What are invariants?

An invariant is a conserved quantity. A simple example comes from micromagnetics, where the magnetic moment vector $\boldsymbol{M}$ can rotate but can't increase or decrease in magnitude; it's invariant in time. If you take the differential equations for the evolution of $\boldsymbol{M}$ and run them through a "black-box" solver such as MATLAB's ode45 or Mathematica's NDSolve, you'll find that the magnitude of $\boldsymbol{M}$ will change in time; depending on the method, it might systematically increase or decrease. That's unphysical behavior, unacceptable in a simulation. We therefore try to devise numerical methods that respect the invariants in the system. The idea goes back a long way – in a primitive form it goes back to Newton! – but as the system gets more complicated than a single magnetic moment, such methods become more difficult to develop, analyze, and solve. A real-world problem might couple multiple types of physics, each perhaps with its own invariance or other requirements, and a good method needs to coordinate those different requirements. In a large-scale problem the equation sets produced can be wickedly hard to solve efficiently.

What professional accomplishments are you most proud of

In research, I'd say it's the work I've done to simplify programming of "physics-tuned" PDE simulation and optimization methods. I started that work while at Sandia and have continued it while at TTU. Beyond that, I'm proud of the work I've done with students. That includes having been a mentor to some exceptionally talented research students, as well as having helped some struggling students improve their work.

What's the best thing about being a mathematician?

The variety of interesting problems! I get to work on research problems in many different fields of science. I'm not an expert in medicine, biology, or engineering, or (at this point) even physics, but I get to work with experts in these different fields and contribute in my own way. I also love teaching and working with students. I can't think of any job more fun than the one I'm doing.

There is a rumor being spread by many of your students that you are the best math professor at Texas Tech, is there any truth to this?

Don't listen to rumors! I'm pretty good at what I teach but there are some math professors at Tech who are truly excellent teachers, far better than me. But I'm always trying to get better, and each semester I try see what does or doesn't work and improve on that. One thing I did take away from my own uninspiring math education before college is that most students like to learn how they're going to use math, so I try to motivate mathematical concepts with interesting applications as much as possible. I think my background in physics along with experience in industry and a national lab help with that.

Student Spotlight: Katrina Webb

By Ethan Bradley

"The glory of science is to imagine more than we can prove." - Freeman Dyson

Often physics is seen as a rigid set of constraints that scientists live in, and must obey. However, many do not see things this way, and Katrina Webb is one such student. Once in a middle school science class, she came across a magazine detailing how NASA was able to put a rover on Mars. She recalls thinking "well the sky's the limit I guess" and from then on she was set on pursuing science. Her call to physics came from a particularly impactful high school physics teacher, where she felt all the pieces she had learned in her previous science classes began to come together. Katrina had always been involved in art throughout her life and saw physics as a natural extension for her creative thinking.

Katrina began her college education at the University of Texas Rio Grande Valley (UTRGV), transferred to UT Austin her sophomore year before taking a gap year. During this time, she remained active in physics by auditing classes and working with UTRGV's CTMO observatory. Then she re-entered college by applying to Texas Tech which she chose because of the community and the facilities available.

Katrina has participated in a diverse array of research projects during her undergraduate career. Her first experience with physics research was working in machine learning applications to detect gravitational waves at UTRGV. She then went on to work at the National High Magnetic Field Laboratory at Los Alamos National Labs, using simulations to prove the efficacy of large magnets to generate energy. Upon coming to Texas Tech, she began a project with Dr. Romano created a program to create tessellations, combining her love for mathematics and art, before eventually ending up working on her current project Muon Tomography. This semester, she has begun work with Dr. Grave-de Peralta on pedagogical approaches to relativistic quantum mechanics. Katrina explains why she enjoys working on so many different topics and projects by saying "I just want to see what's out there!".

Away from the classroom, Katrina can be found painting/sculpting/jewelry making or just participating in anything creative. She also particularly enjoys what she herself deems as 'bad television', saying "It's nice to be able to turn your brain off for a while, it's also just funny!". She is also an avid fan of classic sci-fi, citing Douglas Adams Hitchhiker's Guide to the Universe as her favorite book. Katrina is also an avid animal lover, calling her two cats and pet lizard her best friends.

Upon graduation, Katrina plans to pursue a Ph.D. and become a full-time researcher. She hopes to continue exploring different fields of physics and learning as much as she can. She also wants to keep art an important part of her life as throughout the rest of her career.

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