Radiations

FALL
2021

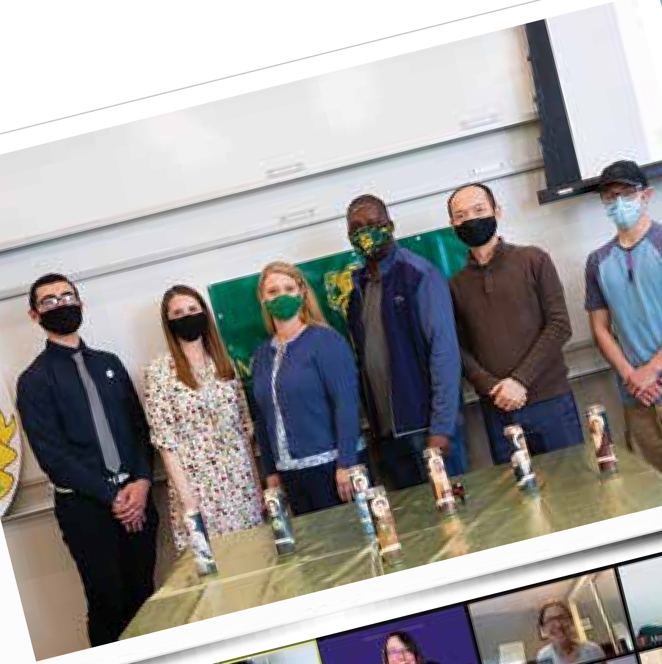
The official publication of Sigma Pi Sigma

A Motorcycle or Bicycle as a Gyroscope (Sort of), Part II

Effects of COVID-19 on Physics Undergraduate Education and Career Preparation

Congratulations

to the newest members of Sigma Pi Sigma
2020-2021 Inductees



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ON THE COVER

Members of the University of Nebraska-Lincoln's SPS chapter participate in a high altitude balloon launch with the UNL Aerospace Club. The launch included several experimental payloads, some designed in collaboration with local high school students.

Photo courtesy of the UNL SPS chapter. @unlsps

INSIDE COVER

Photos courtesy of the 2020-21 SPS chapter reports.

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EDITOR
Kendra Redmond

MANAGING EDITOR
Brad R. Conrad

CONTRIBUTING EDITORS
Andrew Zeidell
Kayla Stephens
Korena Di Roma Howley
Mikayla Cleaver

COPY EDITOR
Cynthia Freeman

ART DIRECTOR
Aaron Hansen

LAYOUT DESIGNER
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SPS PRESIDENT
Kiril Streletzky,
Cleveland State University

SIGMA PI SIGMA/SPS DIRECTOR
Brad R. Conrad

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fax: (301) 209-3082.

LETTER FROM AN SPS ADVISER

Sigma Pi Sigma: 100 Years of Connections

by Gary White, SPS Adviser, The George Washington University and Emeritus Director, SPS and ΣΠΣ

Former SPS and Sigma Pi Sigma Director Gary White at the Bethe House at Cornell University. Photo courtesy of Gary White.

Greetings!

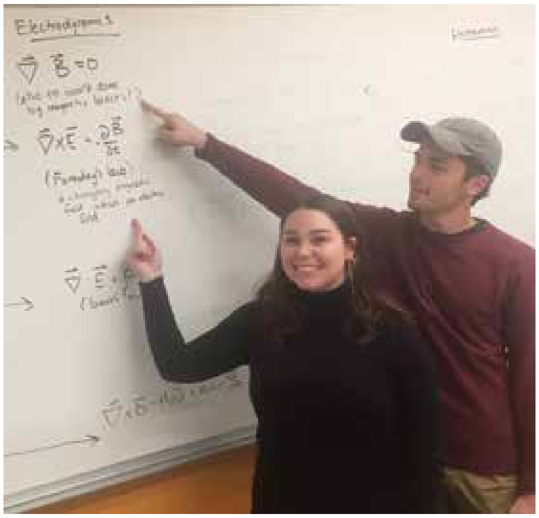
One hundred years of ΣΠΣ—of honor, encouragement, service, and fellowship! I have been remotely aware of things such as a physics honor society for only about half that long, but I am so grateful that an institution devoted to helping undergraduate students and departments has thrived since its earliest days. I am sure that my own path through physics, and those of many of my favorite people, would have been much less interesting, and likely, less *physics-y*, were it not for the successes and the breadth of opportunities that ΣΠΣ spawned. As you probably know, the Society of Physics Students (SPS) was essentially borne out of ΣΠΣ* in 1968. I like to say that SPS and Sigma Pi Sigma are “linked, but distinct,” and both of them have been instrumental for me for decades. I would venture to say that most physicists alive today have been significantly touched by these organizations in a positive way, even if they don’t know it. The two societies exist to support those with an interest in physics and astronomy and make the community a better place.

My first connection to Sigma Pi Sigma was through Cecil Shugart, the first director of the Society of Physics Students, appointed in 1968, and the president of Sigma Pi Sigma from 1972 to 1976. I met him around 1974, I believe, as a middle school student participating in a summer science program (Astronomy!, Electronics!, Atoms!) when he was chair of the physics department at Northeast Louisiana University, now the University of Louisiana at Monroe. I could not have imagined that I would eventually take on that same director role some 27 years later. His sphere of influence (SOI) was large, and even from the margins and at that very young age I could see how much I benefited from his leadership and the strong sense of community he helped to establish.

Speaking of spheres of influence, I invite you to consider for a few minutes your own SOI, not in a self-aggrandizing way, but rather as a fun exercise in visualizing how we impact so many others. Imagine a personal and literal sphere that encloses you, with a radius of a meter or so, which is also the correct size for social distancing! I envision a Gaussian surface like we talk about in my Griffiths E&M class, since I am teaching about that later today.

Now, consider how your personal “sphere” evolves over time. Envision how even as you sleep your personal sphere sweeps out the shape of a curved tube because of Earth’s rotation; if you stay in bed all day on a rotating Earth whose center is fixed, your SOI can be represented by a thin torus—a doughnut of influence, in fact—encircling the whole Earth!

But wait—Earth’s center is not fixed! It has revolved to a new position while you were sleeping, which suggests that the ends of your doughnut will not actually connect and a sort of helical tunnel structure might better represent your personal SOI. Your own helical tunnel of influence (HTOI) will be flanked by many other helical tunnels representing all the other people in your life—numerous HTOIs, like so many fibers in a twisted coil of flat cable.



George Washington University SPS students Erin Mulhearn and Ian Dragulet hard at work discussing surfaces, gradients, and curls in Griffith's Introduction to Electrodynamics course. Photo by Gary White.

Now imagine how these HTOIs change as each person gets up and starts their day, heading to class, getting in a morning run, commuting to work. They begin to weave in and around each other, crossing and separating, intersecting, providing myriad chances to influence each other. Each day produces more twists and interactions among the fibers; what started out as a bit of simple spherical-cow imagery has become an unimaginably connected set of tunnels of opportunity, a weaving together of influences of impossible complexity. And this picture doesn't even consider virtual connections, idea sharing through papers and articles, or higher-order influence effects!

Finally, imagine the 100 years since ΣΠΣ began, in which this bundle of interlocking fibers curves onward in a hundred larger spirals, toward some future that I hope is improved because of the physicists' presence within—because of your influence within!

I hope that you will consider your own HTOI within this bundle and use your influence to help make physics, and the world, a place that is more welcoming, more inviting, and more friendly to all, certainly more so than it has been in the past. What better way is there to realize the four dimensions of ΣΠΣ: honor, encouragement, service, and fellowship? ●

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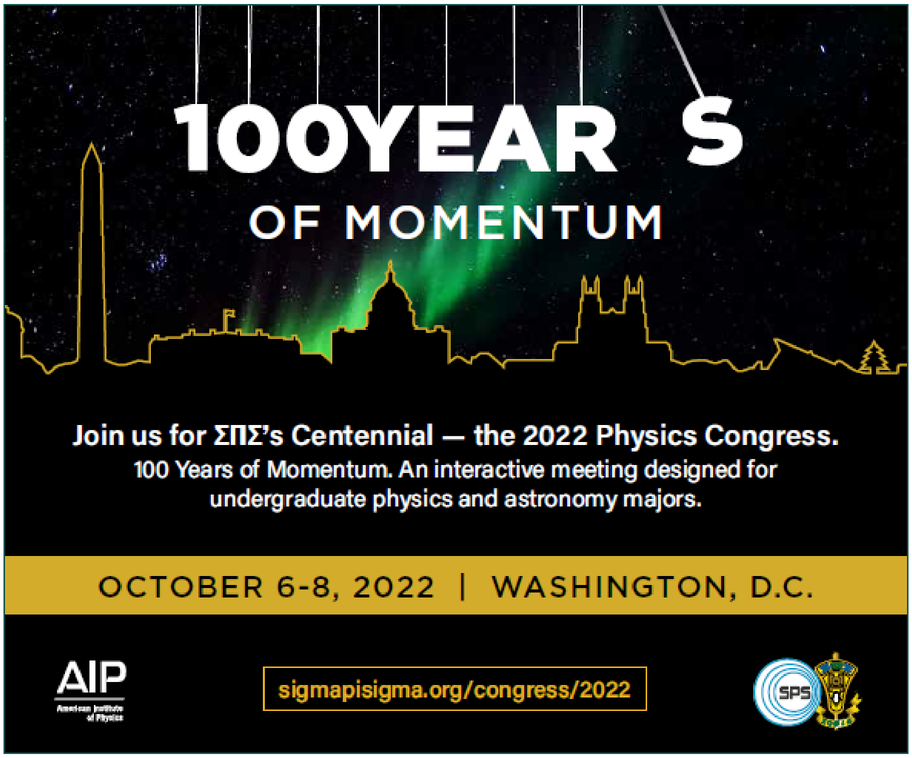
*See the fascinating story of the creation of SPS in D. E. Cunningham, L. W. Seagondollar, C. G. Shugart, A. A. Strassenburg, and M. W. White, "The New Organization of Physics Students," *Phys. Today* 21, no. 9, 59 (1968), doi: 10.1063/1.3035154.



AIP
American Institute
of Physics

The American Institute of Physics is a federation of scientific societies in the physical sciences, representing scientists, engineers, educators, and students. AIP offers authoritative information, services, and expertise in physics education and student programs, science communication, government relations, career services, statistical research in physics employment and education, industrial outreach, and history of the physical sciences. AIP publishes *Physics Today,* the most closely followed magazine of the physical sciences community, and is also home to the Society of Physics Students and the Niels Bohr Library & Archives. AIP owns AIP Publishing LLC, a scholarly publisher in the physical and related sciences. www.aip.org

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Sigma Pi Sigma
Society of Physics Students
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The Congress Centennial Endowment Fund

by Brad R. Conrad, Director of Society of Physics Students and Sigma Pi Sigma

Because of support from ΣΠΣ members and friends of SPS, I am happy to announce that we met our $100,000 fundraising goal and established an endowment for ΣΠΣ's Physics Congress (PhysCon)! The fund, known as the Congress Centennial Endowment Fund, is a tribute to ΣΠΣ's incredible 100-year anniversary and commitment to the success of PhysCon. Through over 800 donations from donors like you, we have ensured the Physics Congress will live on in perpetuity.

The Physics Congress is the largest single gathering of undergraduate physics students in the world where attendees share their passion for all things physics and astronomy. While the first Congress was held shortly after the society's formation in 1928 at Davidson College, today intergenerational attendees within the physics and astronomy communities continue the tradition. Here, students can spend a weekend making important connections, interacting with other scientists and engineers, and hearing from distinguished speakers. This event brings together ΣΠΣ and SPS members from over 300 different chapters from across the world to celebrate our successes and work to advance the society. Our aim is to best serve undergraduate students, faculty, and undergraduate departments.

Every year we encounter students who cannot afford to experience PhysCon without additional support. The Congress Centennial Endowment Fund was created to relieve the financial burden for students who otherwise might not attend the Physics Congress by reducing costs of travel, lodging, and meals. Because of the endowment fund, in 2022 we will be able to distribute over $12,000 toward student travel expenses and ensure that up to 60 students have housing for the duration of the event.

From all of the students this fund will impact, the SPS National Council, and the SPS and ΣΠΣ Executive Committee thank you for helping to make this dream a reality! Please consider joining us in supporting the future of the Physics Congress by donating today at **donate.aip.org**.

TOP: The opening ceremony of the 2019 Physics Congress, with an attendance of 1,200 students and faculty from across ~350 colleges and universities. Photo courtesy of Meg Andersen.

BOTTOM: 2019 PhysCon attendees tour the historic Ladd Observatory at Brown University in Providence, Rhode Island. Photo courtesy of Mary Ann Mort.

Supporting Students in Physics and Astronomy During Challenging Times

It's not easy being a physics and astronomy undergraduate these days. Beyond the demanding curriculum in a normal year, students today continue to face unexpected challenges and situations resulting from the pandemic, climate change, and a shifting world. In addition to the conversion to online learning and discovering that lab time is limited, students have faced ongoing financial impacts, including lost internships and summer employment. Students are reporting increased academic costs, grappling with decreased financial support, and even in some cases facing food insecurity. Each of these challenges raises a barrier between the student and attainment of a college degree.

While American Institute of Physics (AIP) and SPS cannot solve the systemic issues that are causing financial distress for students during this extraordinary time, we can provide immediate support and thereby offset education-related expenses for those who are most in need and at risk of not being able to complete their education due to the effects of the pandemic. In addition, SPS surveys show that about one in five physics and astronomy students report that food security issues are actively impacting their education. More than one in four report the loss of summer funding, internships, or semester employment. To help alleviate this concern, AIP and SPS are in the process of providing seed money for chapters to start Food for Hungry Physics and Astronomy Students or equivalent food cabinets.

AIP-SPS Undergraduate Education Pandemic Assistance Program

The AIP-SPS Undergraduate Education Pandemic Assistance Program was established by AIP, the AIP Foundation, and donors of SPS and Sigma Pi Sigma to assist students in completing their education who have been negatively impacted by the pandemic and economic factors thereof. To help support students to continue their education, SPS will provide financial assistance to students in need.

Food for Hungry Physics and Astronomy Students

The Food for Hungry Physics Students program was established by AIP, the AIP Foundation, and donors of SPS and Sigma Pi Sigma to assist students in completing their education who have been negatively impacted by the pandemic and economic factors thereof. To help alleviate food insecurity concerns for students, the Society of Physics Students will provide $300 in financial support for chapters to start food cabinets for hungry physics students in their departments. Chapters are to use funds for items that are freely accessible to all department undergraduates and are encouraged to fundraise to restock and maintain food cabinets beyond the seed funding. It is our hope that this helps to protect students' and mentors' physical and mental well-being.

If you would like to further the reach of either program, please visit **donate.aip.org** and contribute to the AIP-SPS Undergraduate Student Pandemic Assistance Fund. These funds are directly distributed to undergraduate students and groups. ●

← 2019 SPS summer interns reunite at the 2019 Physics Congress in Providence, RI. Photo courtesy of Megan Andersen.

↙ During Physics Congress workshops, students explore, discuss, create, and hone skills with new friends and future collaborators. Photo by Ashauni Lennox, AAPT.

↓ Students present outreach and local community-building efforts to their peers from around the country during the 2019 Physics Congress. Photo by Ron Kumon.

Gregory Quarles on Careers, Industry, and Failing Fast

A PhD Physicist, Gregory Quarles has worked at federal labs and in academia, at small- and medium-sized businesses, at publicly traded companies, startups, and a nonprofit organization. Given his sector-crossing career, Radiations *sat down (virtually) with Quarles to get some insight on the lesser-known job opportunities for physicists, what it's like to work in industry, and what he's learned along his career path. His answers have been edited for length and clarity.*

Gregory Quarles. Photos courtesy of Quarles of Oklahoma State University's Sigma Pi Sigma Chapter - Zone 12.

What is your current job?

I am the CEO and president of Applied Energetics Inc. It's a publicly traded company in Tucson, Arizona. We develop lasers and other technologies for the Department of Defense and for additive and subtractive manufacturing.

We're a small company and we're growing every day, so I wear many hats. I interface with our customers, meet with leaders at the Pentagon or at higher levels, and meet with other agencies to find out what they need and whether we can provide a solution. I reach out to companies that can supply the parts we need. I engage with the leading US universities doing optics, photonics, and laser-based research to form partnerships and look at the students coming through their pipeline. We're constantly adding new hires.

What kinds of projects is Applied Energetics Inc. working on?

One of the things we're working on is ultra-short-pulse lasers for the defense realm. We're looking at next-generation threats that are very high flying or very fast. How do you deal with swarms of drones? How do you deal with hypersonic missiles that can fly between Mach 5 and Mach 20? Shooting a bullet at a bullet is tough, but could you do something at the speed of light to change its course?

Most of our developments and intellectual property are in frequency-agile sources that operate from the deep UV to the far infrared. In materials processing, manufacturers often use lasers to build materials layer by layer (additive manufacturing) or to remove parts of a material (subtractive manufacturing). Agile lasers are useful because many materials have preferential wavelengths. We can work in realms that some of the normal industrial lasers can't work in as efficiently.

How did your education and career path lead you to where you are today?

When I was five years old, I tried to take apart an air conditioning system. I was a curious kid, always tinkering. I'm sure my parents heard "Why?" and "What?" from the backseat of the car more often than they wanted to.

I grew up in rural Oklahoma. We didn't have AP classes or anything like that, but I was always challenging myself: Where's the biggest challenge? What can I tackle today? One of my physics textbooks had a career section in the very back. It said that of all of the degrees, physics was the hardest path. That's when I decided to study physics.

I started college wanting to study nuclear physics, but then I walked into a laser lab. I saw red, green, and blue light bouncing around. I saw crystals illuminated and all these different colors coming out. And I thought, "I can see this, I can touch this, I can understand this." That was probably the first defining moment in my path.

After earning my bachelor's, I received a fellowship from the American Physical Society to work at IBM for six months. It was another defining moment when I realized that industry could be the right path for me.

I finished my PhD during a low point in the hiring of physicists. Most of the jobs were in federal labs, and I accepted one at the Naval Research Lab. I had a phenomenal mentor who told me to publish, be first author on papers, and give invited presentations. This set me up to gain visibility and build my career early. I stayed there until I was lured away to cofound a startup.

Eventually we sold the startup to a publicly traded company, where I worked my way up to director of research and development. Another defining moment occurred there—we outgrew being a small business. We had supplemented our R&D budget with federal small business grants but couldn't do that anymore. As a result, I was introduced to the world of Pentagon and congressional briefings, talking to congressional subcommittees, and securing funding for research that we could build into commercial and government applications.

I left that company to take my first executive position, as CEO with a defense company. Then I did another startup, sold it, and got a job with The Optical Society (OSA, now Optica) as their Chief Scientific Officer. While there, I spent almost five years trying to understand the different needs of the global optics and photonics community, from sub-Saharan Africa to eastern Asia, from Eastern Europe to the US. That shed light on the need for global solutions and for building a diverse science community, empowering that diversity, and helping others advance their careers through mentorships.

The job with Applied Energetics Inc. came up in 2019. The company had once been thriving but was in a hiatus status. They wanted somebody to kick-start things again, and we've done that. We assembled a really sound board of directors with different backgrounds than mine, we've built up our IP portfolio, and we've found a way to keep everybody safe and employed while being very responsive to our customer base during COVID-19.

An academic researcher might work on the same project for their entire career, but you work on deliverables. What's that like?

We look at what's best for the company and our customer. We may be working on four different sets of deliverables at once, so we have to consider which one has the highest urgency, sufficient funding, and the greatest opportunity to be commercialized. As a publicly traded company, our job is to look at technology that we can roll out to generate cash flow and revenue.

You have to learn to let go. If you see that there's no way to meet financial objectives, technical objectives, or customer expectations, you have to kill programs early. I think that's where the industry mindset and the academic mindset sometimes clash. In industry you fail fast and fail often. If you throw 10 things against the wall and one sticks, you're doing pretty good.

You regularly bring in students to work with you. Why?

I don't think students are presented with a complete picture of what their careers could look like. When you talk to early career professionals, they don't see the nonacademic paths, and that's where 90% of the jobs are located.

I want to expose as many students as I can to industrial research and how it can be just as fulfilling as academic research. When I got the APS fellowship to work for IBM, I had two years of lab experience and one publication from undergrad; IBM handed me the keys to a lab and said, "We need you to do this. Let us know what kind of budget and resources you need."

I had the freedom to learn how to fail fast—come up with a concept, see if it works, throw it to the side if it doesn't work, take the data, and move on to something else. Those are skills you really only get in a setting where you're merging science and engineering.

Quarles speaks to attendees on behalf of Optica (formerly OSA) during the 25th International Conference on Optical Fiber Sensors, held in 2017 on Jeju Island in South Korea.

What do you look for in those students?

Creativity. Being able to think outside of the box when looking for solutions. The ability to explain to a member of Congress what we're doing and why. Every once in a while we need a specialist, but I also want people with a breadth of skills and diverse backgrounds. When it comes to laser engineers, I'm looking for software skills, coding skills, and maybe some materials science or opto-mechanical engineering. I don't want to hire a specialist to fill every one of those gaps.

What would you like academic physicists to know about industry?

There are some tremendous opportunities to work with industry. We have contracts with academic advisors who help us determine whether our concepts can be realized, their limitations, and what areas need research funding. And then we approach agencies and say, "We have this teaming relationship, and we're looking to prove this concept so that it can be used to solve your problem. We'd like you to fund us jointly to work on this." It's not just about fundamental physics, it's also about scaling—how we go from "Yes, it's possible" to "Yes, it's possible and here's a design."

If you're interested in industry opportunities, look at the professional conferences building the foundation of your field, the best ones in the world. Go to where people are trying to move from fundamental research to applications and insert yourself. Networking is key—listening to a talk and going up to the presenter afterwards and saying, "Have you thought about this? Maybe we can work together on trying to find your solution." A lot of industry is open to this approach because it accelerates what they're doing.

What thoughts would you like to leave with *Radiations* readers?

Always ask why. Always look for ways to solve problems and look for collaborations. We tend to try to solve problems by ourselves or with a close group, but bringing in outside voices can help drive your decision-making. Build a team around you that isn't trained just like you. ●

OPTICA | Formerly OSA
Advancing Optics and Photonics Worldwide

Optica (formerly OSA) | www.osa.org

Optica promotes the generation, application, archiving, and dissemination of knowledge in optics and photonics. They serve 22,000 members from more than 100 countries and have student chapters all over the world. SPS student members are eligible for free membership in Optica.

For details visit www.spsnational.org/about/membership/free-ms-membership.

Share Your Career Story

Do you have an interesting career, career story, or career path you'd like to share with *Radiations* readers? Send us an email at sps@aip.org or submit a "hidden physicist" form at tinyurl.com/hiddenphysicist. We'd love to hear from you!

PARTY OF THE CENTURY:

Sigma Pi Sigma Centennial Celebration

by Kayla Stephens, Assistant Director, SPS, and Mikayla Cleaver, Programs Coordinator, SPS

On December 11, 1921, Sigma Pi Sigma, the physics honor society, was founded at Davidson College in North Carolina. Over the past 100 years, we have accomplished so much and evolved into an organization our founders would still be proud of. If they were here today, they would want us to celebrate!

Join SPS and Sigma Pi Sigma on December 11, 2021, to celebrate 100 Years of Momentum. This event will be the kickoff party of the century! There will be SPS party supplies, service award announcements, and a video featuring special guest speaker Willie Rockward, a former Sigma Pi Sigma president, former NSBP president, and Morgan State University physics and department chair.

We invite all SPS and Sigma Pi Sigma chapters across the country to gather together, whether in person or virtually, to help us celebrate! SPS National will be providing boxes filled with SPS- and Sigma Pi Sigma–themed swag and party supplies. Chapters are encouraged to plan their parties anytime beginning November 1 and leading up to the big event on December 11. Take plenty of photos and post them to social media, tagging **@SPSNational**.

In this spirit of celebration, we encourage chapters to nominate people who have made a difference to them for SPS and Sigma Pi Sigma Service Awards. Recipients will be recognized during the session on December 11. We hope to see you there! ●

Texas Lutheran University shows off their Sigma Pi Sigma induction ceremony cupcakes, a change from their normal cake due to COVID protocols! Photo courtsey of Michelle Arguellez and Toni Sauncy, and cupcakes courtesy of Sweet Fountainz, Victoria, TX.

On December 11, visit **www.youtube.com/SPSNational** to join us in celebrating the 100th birthday of Sigma Pi Sigma. Visit **sigmapisigma.org** to request birthday stickers.

To nominate an individual for the SPS Service Award, please visit **spsnational.org/awards/service**.

To nominate an individual for the Sigma Pi Sigma Service Award, visit **sigmapisigma.org/sigmapisigma/awards/outstanding-service**.

EFFECTS OF COVID-19 ON PHYSICS UNDERGRADUATE EDUCATION AND CAREER PREPARATION

The new landscape and recommendations for going forward

by Brad R. Conrad, Director of SPS and ΣΠΣ; Rachel Ivie, Senior Research Fellow, American Institute of Physics (AIP); Patrick Mulvey, Research Manager, AIP Statistical Research Center; and Starr Nicholson, Senior Research Analyst, AIP Statistical Research Center

The pandemic has left no aspect of higher education unaltered. To best serve undergraduate physics majors, we need to expect and plan for changes in the trends in physics higher education and careers. Before the pandemic, long-term shifts in higher education were well underway, including changes to general undergraduate enrollment trends, college education costs, and the backgrounds of the students entering our programs. The pandemic caused immediate and dynamic modifications from what was expected by educators, including additional shifts to total enrollment, shifts in student demographics, and the pertinence of the support structures available to current and incoming students. As classrooms approach their new normal this fall, providing the best education requires being cognizant of these shifts and the educational reality current undergraduate students have experienced for the last year and a half.

Overall trends before COVID-19

From 1999 through the 2020 academic year, the overall number of undergraduates graduating with a physics degree from a US institution has steadily increased.[1] Over roughly the same period of time, the percentages of degrees earned by women[2] and African Americans[3] have stayed roughly flat or even decreased, which is evidence of a systemic problem.

More broadly, while the total number of undergraduates in college rose through about 2010, enrollments have been largely flat since then, with a relatively large decrease expected based on population demographics between now and the end of the current decade. Some models predict, based on the current population demographics, that enrollment changes will not be uniform across institution type. While elite institutions (top 50 ranking) could expect flat enrollments over the next decade, nationally recognized (rankings of 50–100 nationally) and to a larger degree, regular institutions (ranked 101 and higher) could expect large decreases in the number of students who enroll. Correspondingly, as national population trends differ by region, it's to be expected that the impact to departments could be both regional and type specific.[4]

Shifts due to the pandemic

The pandemic caused new challenges and shifts for colleges and universities. Between fall 2019 and fall 2020, there was a total student enrollment decrease of 2.5%. The shifts were not uniform: undergraduate enrollment fell 3.6%, with first-year student enrollment falling 13.1%. The impact on public two-year colleges has also been marked. Overall, two-year college enrollments decreased 10%.[5] Based on national data, we also know that the observed decrease in first-time enrollment is not due to a decrease in high school graduation rates.

There are reported differences in enrollment demographics as well. While enrollment for women is down by less than 1%, enrollment for men is down 5.1%.[4] Fewer low-income students and students from urban settings are enrolling.[6]

Although this enrollment data was not broken down by intended major or at the department level, we should not assume that physics has been unaffected. Rather, keeping these observations in mind at the department planning level is imperative if undergraduate programs are to be responsive to the changing needs of incoming students. As physics and astronomy departments aim to support students who are traditionally underrepresented in physics or who may not feel connected to a department's culture, they must be aware that these students may be even more isolated going forward. In short, incoming students this fall will have a different aggregate profile and may need different resources and support networks to excel.

The physics and astronomy student experience

While some of the effects due to COVID-19 are likely to dissipate, namely, the lack of availability of in-person courses and experiences, the ramifications of being virtual (or hybrid) for an extended period of time will have long-lasting effects in terms of building career skills and fostering student belonging. Experimental course sequences, often built around hands-on skills, public speaking, and group work, had to be substantially modified in many physics and astronomy departments. In a 2020–21 survey by the American Institute of

Physics, 31% percent of departments report that all lab courses were taught virtually, while an additional 52% report that only some in-person activities took place (Fig. 1). In another AIP survey of 2021 college seniors who are physics and astronomy majors, 72% reported that they believed they learned less as a result of classes being switched from in person to online.

Departments should also consider the fact that the pandemic had different effects on different types of students. For example, research has shown that COVID-19 negatively affected women in STEMM fields in multiple ways.[7] AIP's study of senior physics and astronomy majors also shows gender differences in the experiences of women and men as a result of COVID-19. Compared to men, a statistically significant greater percentage of women reported being less confident about doing an excellent job on physics assignments, exams, and labs during the pandemic (Fig. 2).[8]

AIP's TEAM-UP report,[9] the result of a task force study focused on increasing the number of African American students earning bachelor's degrees in physics and astronomy, found that one key factor in the persistence and success of African American students is a sense of belonging to the physics community. In AIP's survey of senior physics and astronomy majors, significantly more non-White than White students reported that their sense of belonging in physics courses or labs decreased during the pandemic (Fig. 3). No student of any race or ethnicity should feel that they do not belong, but the greater likelihood of non-White students to have this experience is especially troubling. Departments should pay special attention to this and consult the TEAM-UP report for recommendations.

Furthermore, the TEAM-UP report notes that various types of support, including academic and financial, are essential for the persistence and success of African American students. However, in the AIP survey of physics and astronomy seniors, 42% of non-White students said that they were in a worse place financially than before the pandemic, compared to 36% of White students. The pandemic also disproportionately affected non-US students; more than 50% of these students said they were financially worse off than before the pandemic.

Other types of support are important for student success. The TEAM-UP study found that for African American students, a sense of connection between physics and "activities that improve society or benefit [the] community" is essential. Therefore, departments should make efforts to support this connection. However, AIP's study of senior physics and astronomy majors found that significantly more non-White than White students reported decreased departmental support for "the work that I want to do in my community" as a result of the pandemic (Fig. 3). There was also a significant gender difference in this perception, with more women than men saying departmental support for desired community work decreased. Furthermore, significantly more women than men reported that their departments created a supportive environment less often during the pandemic than before it started (Fig. 4).

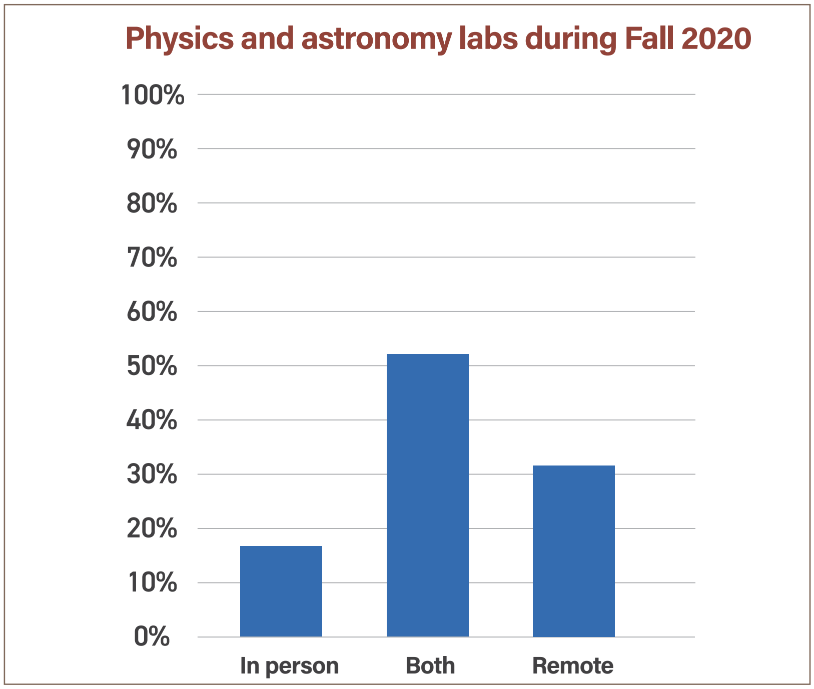


Figure 1. In an American Institute of physics and astronomy survey, 17% of departments reported that during the fall of 2020 all labs were taught in person, 52% reported some in-person lab activities, and 31% percent reported that all labs were taught remotely.

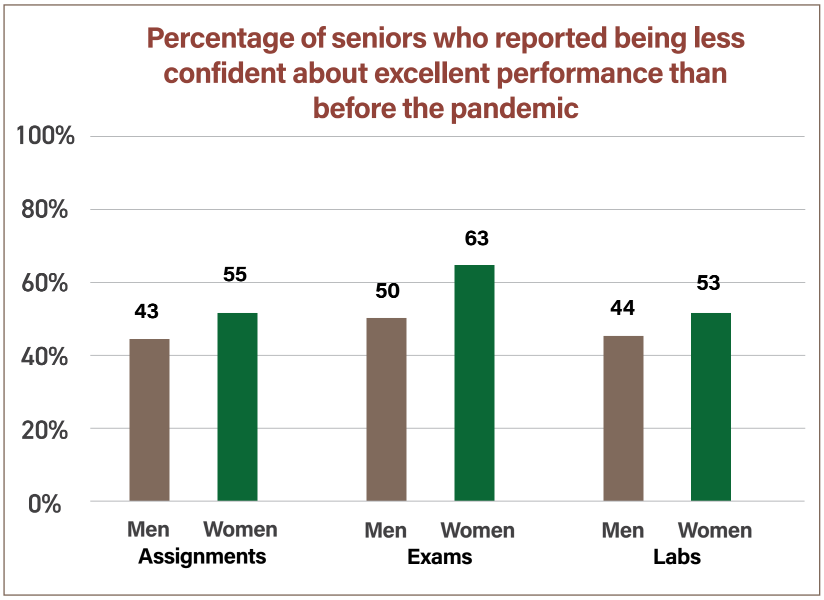


Figure 2. A plot of the percentage of seniors who report being less confident about excellent performance than before the pandemic. In AIP's 2020–21 study, a greater percentage of women reported being less confident about doing an excellent job on physics assignments, exams, and labs during the pandemic.

Findings from AIP's Statistical Research Center show that new physics bachelors who are employed in the private sector report solving technical problems, working on a team, performing quality control, design and development, and using specialized equipment as being some of the most regularly used workplace skills[10]—all of which are honed by experimental courses, group work, and laboratory experiments. Students' access to peer groups has been limited during the pandemic: 54% percent of senior physics and astronomy majors said they never or rarely had access to in-person or online study groups with peers.

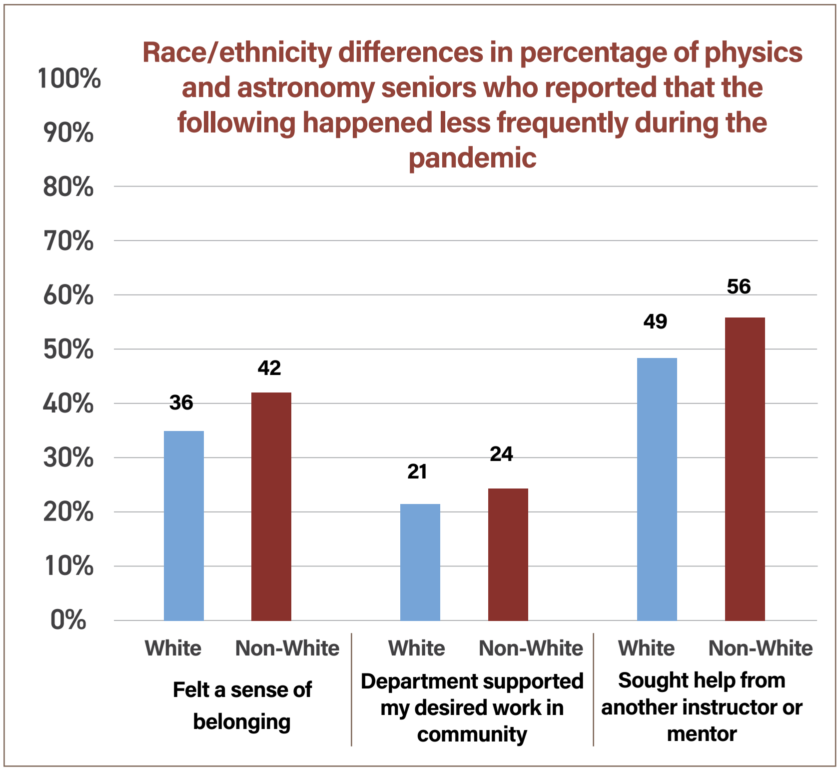
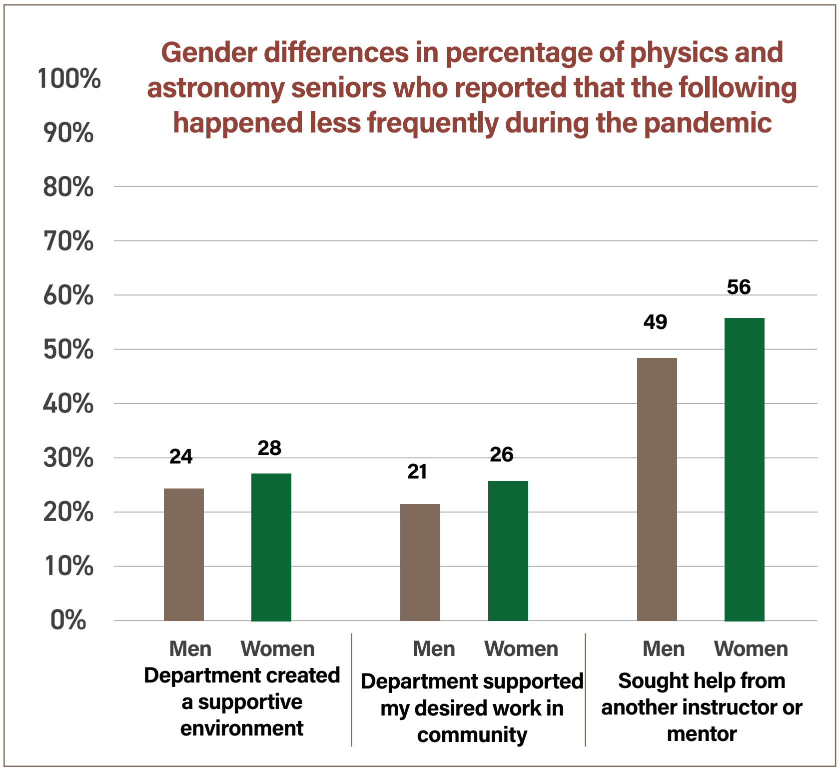


Figure 3. A plot of the differences by race/ethnicity in percentage of physics and astronomy seniors who reported that certain experiences happened less frequently during the pandemic. In AIP's 2020–21 survey, more non-White than White students reported that they less often sought help from another instructor or mentor and that their sense of belonging in physics courses or labs decreased during the pandemic. Non-White students were more likely to report that their department less often supported the work that they want to do in the community than before the pandemic.



Although not part of the survey data, we also know that students have had limited access to research conferences, have not been able to present their work in person, and have not been able to network as easily with other students and physicists who are not connected to the courses they are taking. The AIP senior survey found that higher percentages of women (compared to men) and students who are non-White (compared to White students) report that they less often sought help from another instructor or mentor than they did before the pandemic (Figs. 3 and 4).

Perhaps because of the lack of opportunity to network, senior physics and astronomy majors reported that compared to before the COVID pandemic, they felt less confident that they could get full-time employment in their chosen field (52% of respondents) and less confident that they could get accepted to a graduate program in physics or another STEM field (47% of respondents). While confidence in getting a full-time job could be the result of concern about economic changes due to the pandemic, the lower confidence in being accepted to graduate school could be related to students' perceptions that they learned less during remote classes and labs.

In summary, the fall 2021 semester has a vastly different landscape. Enrollments are down, particularly for the types of students who may need additional support. Returning students report that they learned less during the pandemic, were faced with fewer opportunities to connect with other students and faculty members, and have concerns about getting a job or being accepted into graduate school. Some of the pandemic effects were greater for students from underrepresented groups, who report a reduced sense of belonging, less confidence in their ability to succeed in school, and being in a worse place financially.

Areas of consideration

As a result of these changes, we offer some areas for consideration by undergraduate departments:

1. The changing demographics of those entering their programs: How can we support students at risk of being isolated or who feel like they don't belong? How might we adjust our recruiting efforts in light of the new enrollment landscape?
2. Equipping students with a well-rounded skill set: How do we adjust courses and extracurricular offerings, and help students develop skills that were missed because of the pandemic?
3. Supporting vibrant undergraduate groups and student

Figure 4. A plot of gender differences in percentage of seniors who reported that certain experiences happened less frequently during the pandemic than before. In AIP's 2020–21 study, significantly more women than men reported that their departments less often created a supportive environment and supported their desire for work in the community during the pandemic than before it started. Women also were more likely than men to report that they less often sought help from another instructor or mentor than before the pandemic.

leadership: How can faculty engage with and support a sense of student community? How can we help second-year students fully engage in the community after their nontraditional first year? How do we encourage students to form study groups and seek academic assistance from faculty after a year of isolation? Does the department build strong connections to our undergraduate student leaders? How are we connecting students to community or university resources that will support them as people and researchers?

4. The unequal impact of COVID-19 on different groups of students: How can the department increase student belonging and foster success for women and students from other minoritized groups? How can we help students under heavy financial burdens feel that they belong in physics and continue their physics education?
5. Student preparation for the workforce and graduate school: How can we help students build confidence in their knowledge, skills, and abilities? How can we set them up for success in job seeking and applying to graduate programs? How can we equip them to discuss the impact of COVID-19 on their education in productive ways with potential employers and graduate departments?
6. Support undergraduate research: How can we increase hands-on research opportunities for students who weren't able to participate during the pandemic, or who had to switch to computational or theoretical research projects? How can we help students who weren't able to participate in hands-on research projects learn about research careers?

Awareness of changing enrollment trends, demographics, and student experiences should lead departments to make changes that respond to these findings and further support students as we move forward. Thoughtful planning and the realization that it's not "business as usual" will help not only students, but also departments looking to recruit, retain, and serve physics and astronomy graduates in the postpandemic world.

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https://physicstoday.scitation.org/do/10.1063/PT.6.5.20211102a/full/

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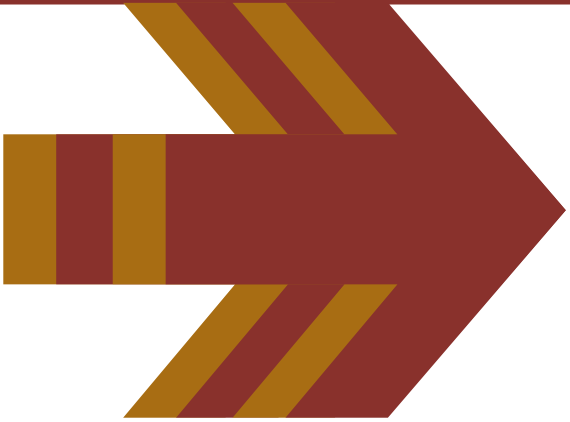


MY "WOODSTOCK"

The summer of 1969 through the eyes of an undergraduate physics major

by David M. Pepper, Owner, Physicist, Inventor, and Consultant, Malibu Photonics

Ever since I was a kid at Hancock Park Elementary School in Los Angeles during the 1950s, I have loved science. I watched Mr. Wizard on TV and read his newsletters, got monthly "Things of Science" experiments by mail, looked at "The Amateur Scientist" in *Scientific American*, and read science books for kids by science writer Kenneth Swezey.

My teacher allowed me to perform science experiments in front of my classmates in the fourth grade, the year 1959. They called me "the scientist." In one experiment I built a cloud chamber—using dry ice and a jar of saturated alcohol—to view cosmic ray tracks (elementary particle tracks). Unfortunately, the experiment didn't work, but I freaked out my classmates by placing small chunks of dry ice in the boys' bathroom toilets. Needless to say, I met the principal that day!

Just 10 years after my unsuccessful cloud chamber experiment, I would find myself at the frontier of physics, performing experiments on elementary particles at SLAC. From Woodstock, Vietnam, and Nixon to the Beatles and the Stones, the Apollo 11 lunar landing, and the World Champion Mets and Jets, 1969 was a dynamic year. As music rocked Woodstock, I would be having an unforgettable, incredible summer at one of the world's most powerful accelerators. It was my Woodstock.

Top: An aerial view of the SLAC facilities. Photo by Brad Plummer, SLAC National Accelerator Laboratory.

Inset: Woodstock, a music and art festival held in August of 1969, attracted more than half a million people and featured iconic performances by Richie Havens, Jefferson Airplane, Jimi Hendrix, Janis Joplin, and many others. In this photo the stage is on the left and the camping area is in the distance. The towers were for light and sound. Photo by Woodstock Whisperer, licensed under CC BY-SA 4.0.

Spring of 1969

After graduating from Fairfax High School and completing two years at Los Angeles City College, I transferred to UCLA to complete my bachelor's degree in physics. It was the spring of 1969, and I wanted to work in the physics department for the summer. I had just aced Physics 105A, Classical Mechanics, taught by (the late) Professor Darrell Drickey. I scheduled an appointment and asked him if there was anything I could do over the next three months.

I had zero ideas about current research. Wasn't everything already discovered and investigated? What was left to do in mechanics, thermodynamics, electricity and magnetism, or optics? And I hadn't yet heard of quantum mechanics. Maybe I could clean test tubes or measure the Q of oscillators?

Professor Drickey sensed my naïveté and invited me to spend the summer at SLAC doing high-energy physics. I had no idea what SLAC was or what high-energy physics entailed, and I had never lived anywhere but with my parents. Professor Drickey suggested that I pack my bags, drive up to Stanford, and help run an experiment to uncover the physics of the neutral K-meson (K^0) decay . . . whatever *that* was![1] How exciting and scary—to leave home and do something when I had no idea as to its meaning (remember, this was more than 25 years before Google and smart phones!).

Two weeks later, my mom was waving goodbye in my rearview mirror as I drove north in my 1967 Mustang. A nice lady named Mrs. McKay rented rooms to summer students in her turn-of-the-century, multibedroom house in Palo Alto. She became my second mom that summer.

Day 1

As I drove into work on my first day, a sign said that SLAC was administered by the AEC, the Atomic Energy Commission. This would bring Vietnam protesters to picket in front of the facility, believing it was home to atom bomb research. At the time, SLAC stood for the Stanford Linear Accelerator Center. The facility is now the SLAC National Accelerator Laboratory, administered by the US Department of Energy.

The main facility consisted of a two-mile-long electron accelerator housed in a kind of copper tube, under high vacuum, buried 30 feet underground and aligned to within fractions of a millimeter of a straight line. The final electron beam energy was 16 GeV (GeV = one billion electron volts), the world's highest energy electron beam

An aerial view of the SLAC facilities. The electrons started at (A) and traveled for 2 miles before reaching (B) with a beam energy of 16 GeV. The beam was then split and sent to different experiments; ours was housed at (C), known as End Station B. Photo by Brad Plummer, SLAC National Accelerator Laboratory.

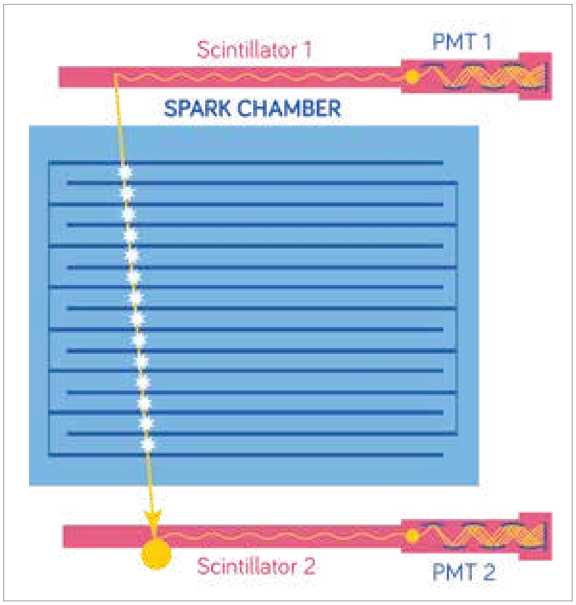
at the time. At the end of the accelerator was a collection of concrete buildings, called end stations, that held experiments performed by international collaborations. A "switchyard" directed the beam to the various experiments in the yard. Our experiment would take place in End Station B.

I met the team members that first day: physics faculty members from UCLA, Johns Hopkins University, the University of Greece, and the Naval Post-Graduate School in Monterey, among others. I had a vantage point from the shoulders of giants that summer—I came in knowing nothing about quantum mechanics or particle physics.

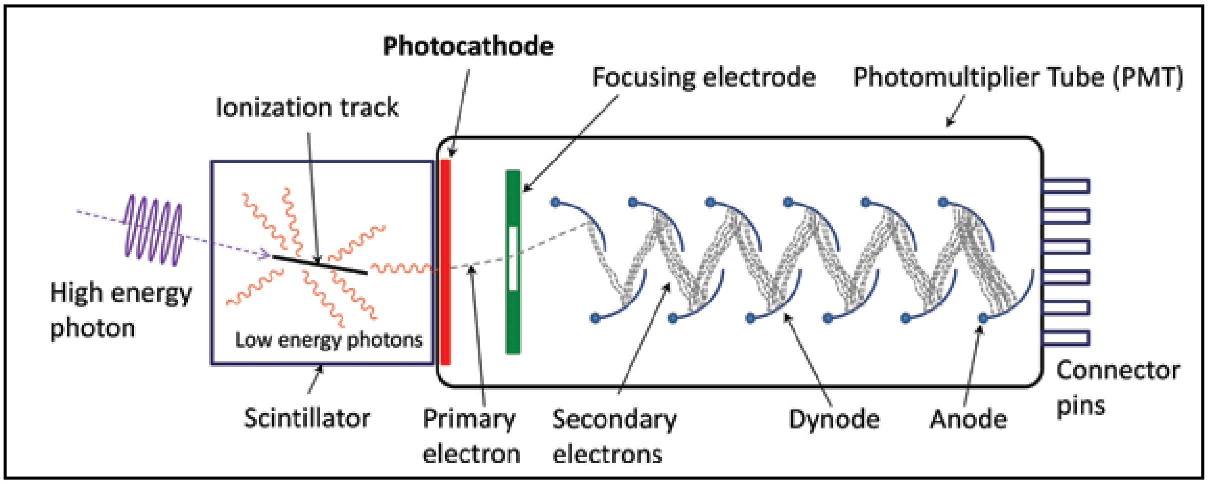
The experiment

I learned quickly and soaked up the physics. In End Station B, the 16-GeV electron beam collided with a block of beryllium (Be). This collision produced a plethora of subatomic particles—protons, neutrons, electrons, and an alphabet soup of mesons—that entered a second concrete room where our experimental apparatus was housed. That's where the fun started!

The goal of the experiment was to investigate the physics of a neutral elementary particle, the K-meson, to determine its so-called form factor.[1,2] As it travels, the K-meson decays into various other elementary particles. We studied a specific set of decay modes.



In this illustration of a spark chamber, a charged particle (the big yellow dot) propagates in a downward (vertical) direction, leaving a path of ionized atoms in its wake. If a signal is present in both scintillator detectors (small yellow dots), a voltage is triggered across the chamber that causes the ionized atoms to spark (white stars). The trail of sparks then reveals the particle's trajectory. Image adapted by AIP from a fair use illustration.



A schematic view of a scintillator coupled to a photomultiplier tube (PMT). High-energy radiation enters the scintillator and emits a flash of light. The signal is captured and amplified by a PMT, then read out and recorded by the experiment. Image by Qwerty123uiop, licensed under CC BY-SA 3.0.

- The decay of a neutral K-meson to a positively charged pi-meson (π^+), an electron (e^-), or a muon (μ^-), and the corresponding neutral and nearly massless neutrino (the electron neutrino, ν_e, or the muon neutrino, ν_μ), as well as its antiparticle counterparts π-, e^+, or μ^+ and the respective antineutrino.
- The decay of the neutral K-meson to a π^+, π^- and neutral pi-meson, π^0.

The former, which is discussed in this article, is analogous to a cue ball (the K-meson) spontaneously fragmenting into three new billiard balls: a pi-meson, an electron (or a muon), and a neutrino.

There were two different types of neutral K-mesons generated by the Be collision: the so-called K-zero-long (K^0_L) and K-zero-short (K^0_S), with decay times of 50 ns and 90 ps, respectively. Our detector was in a building a distance from End Station B such that the K^0_S mesons would have long since decayed and we could investigate primarily the K^0_L mesons. Isn't nature wonderful?!

Our apparatus

Our basic apparatus consisted of two sets of so-called spark chambers (wire chambers) that sandwiched a magnet about 30,000 times stronger than the Earth's magnetic field. Each spark chamber consisted of a thin layer of gas—a mixture of helium-neon atoms—bound by screens; it looked like a thin window with screens on both sides. When a charged particle traversed a spark chamber, it left a track of ionized gas that sparked when there was a voltage pulse across the chamber. The coordinates of the spark (and, hence, the location of the charged particle) were determined by which wires carried the current pulse.

Imagine throwing a baseball through a sequence of windows, creating a hole in each window. The path of the holes in the windows reflects the baseball's trajectory. Similarly, the path of the sparks in the chambers reflected the charged particle's trajectory. Using a 3D reconstruction code, we could connect the sparks to reveal a particle's trajectory.

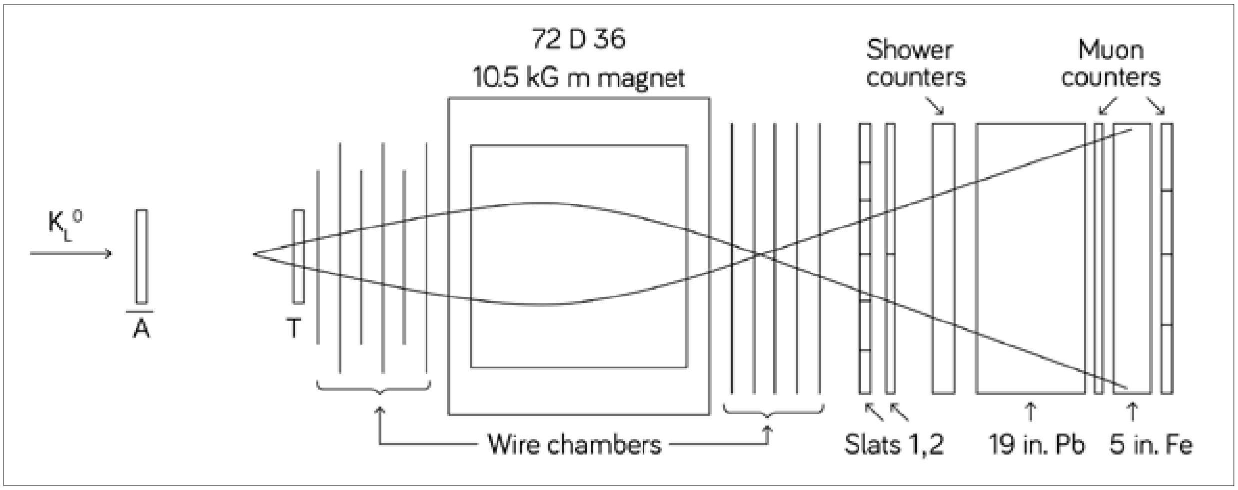
After passing through the first array of spark chambers, the particles traveled through the magnet. A magnetic field curves the path of charged particles—positively charged particles curve opposite to negatively charged particles, while neutral particles are unaffected. The greater the momentum of a particle, the less the magnet curves its path. A second set of spark chambers came after the magnet so we could collect curvature data. From this we could determine the momentum and charge of a particle.

Next, the particles passed through scintillator detectors arranged in crisscrossed slats to create a checkerboard pattern. A scintillator is a material that emits a pulse of visible light in response to high-energy radiation. In scintillator detectors, this pulse of light is captured, amplified, and outputted by a photomultiplier tube (PMT). Since photomultiplier tubes are so sensitive to light, we wrapped the scintillator detectors in black tape. The tape didn't impede the particle's path but blocked the room light so that the scintillator was light-tight.

When a charged particle passed through a checkerboard square it generated a minute flash of light, a detectable pulsed signal; when a neutral particle passed through it left no signal. The K^0_L decays resulted in a pair of charged particles—a pion and either an electron or a muon—and a neutral neutrino, so a desired event triggered two squares simultaneously: one left of center and one right of center.

From there the particles encountered a so-called shower counter. Made of thin lead sheets (absorbers) and scintillator detectors, the shower counter differentiated electrons from other charged particles. Electrons generated a much larger "shower" of gamma rays and charged particles than pions and muons, which we could see in the PMT signals.

The final piece of the apparatus was a muon counter. This was comprised of a 19-inch-thick wall of lead bricks, a 5-inch-thick wall of iron, and scintillator detectors. The two walls blocked gamma rays and most charged particles, but not muons. The muons passing through were subsequently detected by scintillator detectors.



Top view of the experimental apparatus. A desired decay event would not trigger the upstream scintillator detector A but would trigger scintillator detector T and the checkerboard slats. Once triggered, a voltage pulse would be applied to the spark (wire) chambers, resulting in a sequence of sparks indicative of the trajectory of the charged particles. Image by Drickey et al.[1]

Data collection

The combination of signals from the checkerboard detector array and two scintillator detectors upstream of the spark chambers, noted as *A* and *T*, respectively, was digitally processed in a logic tree, thus determining which "events" to record and which events to discard. The space between scintillators *A* and *T* is where a K^0_L would decay from a neutral particle into charged particles.

For example, a K^0_L would not trigger *A* since it carries no charge; we'll call this result [NOT A]. Once it decayed, the resulting charged particles would trigger the downstream detector *T*, yielding the result [T]. Because of their opposite charges, they would also trigger the left and right sides of the checkerboard array, namely, [Left] and [Right]. Hence, the combined triggers [NOT A] and [T] and [Left] and [Right] would indicate a K^0_L decay of interest.

Since the trigger scintillators, digitizing electronics, and logic gates performed much faster than the spark chambers, shower counters, and other pieces of the apparatus, there was adequate time to decide whether or not to record a given event using the logic tree. If yes, the spark-chamber coordinates, shower counter signals, and muon counter signals would be recorded, along with information for real-time beam monitoring.

Over the summers of 1969 and 1970, we recorded about 420,000 K^0_L events on magnetic tape. We used a Hewlett-Packard HP2116B computer—the company's first computer, which was state of the art at that time. It used 16-bit words, had 16 kB of memory, and ran at a clock rate of 1 μs. It required large reels of magnetic tape to record the data. By comparison, a typical smartphone uses 32-bit or 64-bit words, has approximately 10 GB of memory, runs at a clock rate of 1 ns, and can record 1 TB of data on a thumb drive!

In this 2006 photo, Rutgers University graduate student Tim Koeth (now an assistant professor at the University of Maryland) sits between the poles of the Chicago Cyclotron Magnet at Fermi National Accelerator Laboratory. This type of magnet is typical of those used in high-energy physics experiments at the time of our SLAC experiment. Photo courtesy of Timothy Koeth.

Conservation and form factors

The conservation of energy and momentum is a pillar of the physical laws. It can apply to billiard balls as well as to elementary particles. Using these conservation laws, all of the decay-mode products could be determined and tabulated for each event. Since the particles traveled at nearly the speed of light, the energy and momentum were relativistic in nature and Einstein's famous equation, $E=mc^2$, applied. It's interesting that such basic physical laws apply to this otherwise complex system and apparatus.

To uncover the physics of the K^0_L meson decay, the team mapped various functions of the energies and momenta of the decay modes—the mass of the K^0_L, the energy/mass and momenta of the charged pion, the electron or muon, and the neutrino—in a two-dimensional plot. One important mapping was the Dalitz plot.[3,4] On the Dalitz plot, each of our events was represented as a point, and the distribution of points indicated whether resonances, new particles, or form factors were present—a goal of the experiment.

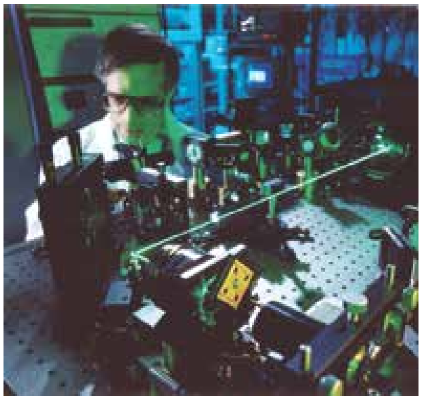
In one case the distribution of the π, e [μ], and neutrino events (technically the square of the momentum transfer) was proportional to something called the strong interaction form factor. Determining form factors constitutes one of the key parameters of particle interactions.[1] Experimental form factors can be compared against theory to test our understanding of the underlying physics and refine our models.[1,2] As it turns out, the form factor was proportional to the shape and size of an elementary particle.[2]

This complex system is roughly equivalent to a cue ball (K^0_L) spontaneously fragmenting into three new billiard balls. Each such event results in a different energy distribution of the three balls, which also depends on the detailed shape of the billiard balls from purely spherical.

Detective work

During the summer months of 1969, the experiment ran over two-week periods, 24/7, after which we had a week to get ready for the next run. I worked the graveyard shift, from 4 a.m. to noon, with Professor Chuck Buchanan. I loved interacting with him, as he taught me the essence of the physics and how the system was calibrated. Many of his notes were written on the cardboard backing of notepads, the proverbial back-of-the-envelope, which I kept in my diary for posterity.

At one point, during a sequence of several days, we noted that the shower counter pulses from one of the detectors were abnormally high for an hour or so, so we had to scrap the data. I set out to determine the basis of this systematic problem. Eventually I noticed that shortly after sunrise each day, a sliver of sunlight entered the building and shone on the apparatus for about an hour. This sliver of sunlight hit the shower counters, whose PMTs were wrapped in black tape—but one PMT had a small opening in the tape. I was able to correlate the anomalous detector signal with that ray of morning sunlight! When I shared this with Professor Buchanan, he thanked me for my detective work. Even though I didn't understand the detailed physics of the K-meson experiment, I took pride in preventing valuable data from being discarded: my moment of glory!



David Pepper performs laser-based ultrasound experiments during his time at HRL (formerly Hughes Research Laboratories). Photo courtesy of Pepper.

David Pepper next to a poster at HRL of his January 1986 article in *Scientific American*, "Applications of Optical Phase Conjugation," translated into various languages. Photo courtesy of Pepper.

Summer's end

That summer was so exciting and memorable that I captured it in the only diary that I ever created. The diary consisted of my layman's description of the experiment and the basic underlying physics, as well as photos of the apparatus and gatherings that we had that summer. The physics team was like family to me, a very intimate, wonderful, and supportive group of faculty, postdocs, and students. I treasured the diary for decades and shared it with friends and colleagues.

Unfortunately, the diary and all my worldly possessions were lost in the Woolsey Fire of 2018. Still, the fond memories of that marvelous summer remain embedded in my memory.

Epilogue

After that wonderful experience, I returned to UCLA and became a junior member of the high-energy physics group, assisting with data analysis—think stacks of computer punch cards, huge tapes of data, and Fortran statements. The following summer I joined the group at SLAC for another two months of "phun" and physics in End Station B.

After earning my bachelor's in physics from UCLA, I studied nonlinear optics at Caltech. My PhD thesis was in the emerging area of wavefront reversal, or phase conjugation, of laser beams. One can say that I went from one elementary particle (the K-meson) to another elementary particle (the photon).

I had the honor to work at the Hughes Research Laboratories (now HRL Laboratories), where the world's first laser, the ruby laser, was demonstrated by Ted Maiman in May of 1960. I spent my entire career at HRL working on such projects as phase-conjugate optics, adaptive optics, compensated imaging, laser-based ultrasound, and photonic communications. After retiring, I started Malibu Scientific, through which I do consulting on laser and photonics technology as well as intellectual property. I live with my dear wife, Denise, and our rescue doggie, Kirby. ●

Acknowledgments

I am forever grateful and thankful to my dear parents for providing me with the support and inspiration to pursue my dreams. Chuck" D. Buchanan and the late Professor Darrell J. Drickley became my mentors during my stay at SLAC and UCLA, and were very influential in my decision to pursue physics. I am truly indebted to them as teachers and as friends—their guidance was invaluable.

Notes

The summer of 1969 was truly a highlight of my life. The intent of this article is to express my excitement, enthusiasm, and inspiration for learning about what physicists do at a national laboratory, high-energy particle accelerators, the interactions of elementary particles, and this particular experiment. As such, the physics is written in layman's terms through the eyes of a third-year undergraduate physics student and may not be 100% accurate.

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Share your undergraduate research story

Whether it was five months or 50 years ago, we'd love to hear about an undergraduate research experience that was meaningful to you! Submit stories, pictures, and/or reflections to **sps@aip.org,** and we may feature them in the Spring 2022 issue of *Radiations*.

Sigma Pi Sigma Chapters Honor Outstanding Service

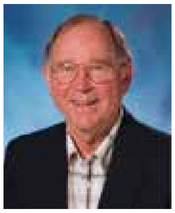
Each year, Sigma Pi Sigma Outstanding Service Awards are presented to individuals and groups who have performed meritorious service to the field of physics and/or the society at the local, national, or international level. Awardees can be chosen by a Sigma Pi Sigma chapter or group of chapters for their positive impact and, if not already members of Sigma Pi Sigma, may be received into membership when the award is presented.

This fall, the SPS and Sigma Pi Sigma Executive Committee recognizes several recent recipients of this high honor.

Jim Porter

Awarded by the ΣΠΣ chapter at Abilene Christian University (ACU)

Award citation



For his longtime support of the Department of Engineering and Physics at ACU. Mr. Porter helps build relationships and stimulate entrepreneurship among our students, faculty, and staff. Mr. Porter has supported faculty members during their sabbaticals, contributed to our capital campaign for new science buildings, and helped to launch the Nuclear Energy eXperimental Testing Lab (NEXT Lab).

Biography

Jim Porter graduated with a bachelor's degree in industrial engineering from Texas A&M University, then earned an MBA from Harvard University. Later, he attended Stanford University's Advanced Management Program and Babson College's Entrepreneurial Education Program. A former Air Force captain, Porter has always maintained a healthy mix of commercial business and "give back" activities. He was a principal participant in two early-stage companies and directed Wall Street public company fundraising of about $500 million. He has extensive merger and acquisition experience and served for five years as entrepreneur-in-residence on the College of Business Administration faculty at ACU. Porter is a trustee of ACU, a member of the NEXT Lab Oversight Committee, and the principal and owner of Porter Capital Partners.

David Halbert

Awarded by the ΣΠΣ chapter at Abilene Christian University (ACU)

Award citation

For his support for the mission of Abilene Christian University (ACU), the Department of Engineering and Physics, the NEXT Lab, and his humanitarian efforts.

Biography

David Halbert is a graduate of ACU and the University of Texas Medical School. He served as captain and flight surgeon in the US Air Force, and as a general surgeon in Abilene, Texas, for more than 40 years. He has started several companies and currently serves as president of Clavél Corporation. Halbert's quest to address the root causes of extreme poverty globally led him to study clean, safe, and affordable energy sources. After learning about the promise of advanced molten salt reactors, he was instrumental in forming the Nuclear Energy eXperimental Testing Lab (NEXT Lab) at ACU. Halbert was the first to contribute funding to the project and continues to serve on the NEXT advisory board.

Brittney Hauke

Awarded by the ΣΠΣ chapter at The Pennsylvania State University

Award Citation

For fully exemplifying the pillars of service through their steadfast dedication. They are always one of the first people to volunteer their time and efforts to the society.

Biography

Brittney Hauke is a PhD candidate in materials science and engineering at Penn State, where they study the fundamentals of glass relaxation and how it impacts glass properties. Hauke graduated with a master's in materials science from Arizona State University in 2019 and received bachelor's degrees in both physics and studio art from Coe College in 2017. Hauke has been a local and national leader in SPS since they were an undergraduate and is currently serving on the 2025 Physics Congress Executive Program Committee. They also served on the programming committees for the 2016 and 2019 Physics Congresses. In their free time, Hauke draws digitally and traditionally, paints with watercolors, and dabbles with photography.

Stephen J. Mackwell

Awarded by the ΣΠΣ chapter at The George Washington University

Award Citation

In recognition of his many years of support of student involvement in physics and astronomy, his leadership and support for SPS and Sigma Pi Sigma, and dedication to the pillars of Sigma Pi Sigma.

Biography

Stephen Mackwell is a former faculty member at Pennsylvania State University and Bayerisches Geoinstitut in Bayreuth, Germany. He served as corporate director of science programs at USRA, an independent, nonprofit research organization founded in 1969 by retired NASA administrator James Webb and Rockefeller University president (and former AIP board chair) Frederick Seitz. Mackwell is a fellow of the American Association for the Advancement of Science, the American Geophysical Union, and the Mineralogical Society of America. In 2016, the International Astronomical Union recognized his contributions by naming Asteroid 5292 Mackwell in his honor.

George F. Spagna

Awarded by the ΣΠΣ chapter at Randolph-Macon College

Award Citation

For 30 years of dedication to the ΣΠΣ chapter of the Randolph-Macon Department of Physics, Engineering, and Astrophysics and upholding the pillars of Sigma Pi Sigma.

Biography

George Spagna was a physics faculty member at Randolph-Macon College for 35 years. During this time, he served as director of the Keeble Observatory, facilitator of the astrophysics minor, physics department chair, and Sigma Pi Sigma advisor. Spagna was devoted to increasing the public's understanding of science and to making physics more inclusive and diverse. For example, he modified an astronomy course for the visually impaired and served on several committees to improve the college climate for minorities. As the longtime director of the Keeble Observatory at Randolph-Macon, Spagna spearheaded a major overhaul of the facilities. The new observatory, built in 2017, houses a state-of-the-art Ritchey-Chretien telescope with a 40-cm primary mirror—the largest telescope between Washington, DC, and the Blue Ridge Mountains.

How Research Reaffirmed My Love of Teaching

by Carissa Giuliano, SPS Member, Adelphi University

Carissa Giuliano. Photos courtesy of Giuliano.

Since the moment I stepped into my first physics class, I've wanted to pursue physics as a career. I loved every part of high school physics—the rigor, the elegance with which physics describes the universe, and, if I'm being honest, how fun the labs were. I knew I wanted to be a physicist but wasn't sure where to go from there. I considered becoming an engineer, researcher, or teacher—the only physics careers I thought existed at the time.

Engineering wasn't for me, but I couldn't easily rule out research or teaching. I enjoyed peer tutoring and eventually decided that teaching would be best. I planned to major in physics and minor in adolescent education, a somewhat haphazard decision that launched me on the path to my future dream career—though not a straight, clear path.

I entered college with a relatively narrow goal: to teach high school physics. This single-mindedness persisted until my professor and future mentor, Dr. Matt Wright, asked me about my career aspirations. I told him my plan, and though he was supportive, he also encouraged me to keep an open mind. He suggested that college was the time to try a little bit of everything and worried that if I was too focused on teaching, I might miss an opportunity to explore another potential dream career.

I didn't realize it until then, but this had been a nagging fear at the back of my mind. I followed Professor Wright's advice and sought out non-teaching-related endeavors. As I learned about the plethora of careers available to those who study physics, I ruled out most of them—but not research. The following semester Professor Wright became my research advisor. My project involved both physics and teaching: I would conduct research on the physics of smell and present my findings at national conferences and other events.

Preparing for my research presentation included devising hands-on materials such as 3D-printed parts of the nose, as well as animations. I enjoyed both the research and teaching aspects of the project, but my favorite part, by far, was giving the presentation. Each time, I felt what I now call a "teacher's high." I was in the zone and passionate about what I was doing. It seemed as though teaching was still the right career path for me.

Still, I couldn't shake the feeling that I hadn't experienced enough of the research world to completely rule it out. My smell project had given me only a small glimpse into research, and I felt that one more experience would help to solidify my career goals.

At this point, I was about halfway through college and the demands of the teaching program were growing more intense. I didn't have much time left to explore other career options. After receiving advice from Professor Wright, I decided to apply for a Research Experience for Undergraduates (REU) position. REUs are competitive, 10-week summer research programs at schools and labs around the US. To my delight, I was accepted by Boston University's REU program for the summer of 2020.

Typically REU students live at or near their research institution during the program, but due to the pandemic, my REU became remote (I was lucky—some were canceled altogether). Part of me was disappointed that I wouldn't get the full REU experience, but there was a silver lining: I had the incredible opportunity to conduct research related to COVID-19. I was ecstatic to study something so novel and pertinent. If any experience could convince me to become a researcher, this was the one.

At the end of the summer, I presented my research to an audience of professors, fellow undergraduates, and family and friends. I knew that this would be the deciding moment. If I enjoyed giving the presentation more than doing the research, I was going to stick with teaching. If I enjoyed the research more, I'd consider following that career path.

As I started planning and rehearsing the presentation, I felt that teacher's high again. I enjoyed the research, but the joy I got from presenting and teaching was decidedly greater. Teaching gave me a feeling that no other career trial had. That's when I finally knew for sure that I was meant to teach.

I wouldn't have reached this moment of clarity without following Professor Wright's advice to pursue research. At the beginning of college I set out to become a teacher solely because, based on my limited knowledge and experiences, it seemed like the best option. Now, as I'm nearing the end of my undergraduate career, I can assuredly say that I know I'm where I'm supposed to be. Teaching is my passion and unquestionably the right career for me. ●

ABOVE: Giuliano presents her work on smell at the 2019 Physics Congress. She is holding a model of a molecule that can represent either nickelocene or ferrocene—molecules with similar structures but different smells. The laptop and laser demo illustrate inelastic electron tunneling, and the white and blue pieces on the table are 3D-printed olfactory receptors.

Centennial Voices

In honor of the centennial of Sigma Pi Sigma, SPS and ΣΠΣ members have been sharing what the societies mean to them and how their lives have been impacted. To add your voice, visit **tinyurl.com/sigpisig100survey**.

Being inducted into Sigma Pi Sigma was the best thing that happened to me. It led me to an internship in my junior year and graduate school admissions both in the US and United Kingdom.

Shouvik Bhattacharya, Inducted at Minnesota State University Moorhead, 2011

Getting to be a leader within SPS has always meant a lot to me. When I was younger I met a lot of other SPS leaders that I continue to look up to, and I hope that I can also be a role model for current students. I'm also honored to be able to work with some of the nicest and most inspiring physicists in the field through SPS!

Brittney Hauke, 2019 Physics Congress Planning Committee Member, 2025 Physics Congress Co-Chair, Coe College, 2016

While undergraduate physics programs give students the technical skills needed for a physics career, SPS and Sigma Pi Sigma chapters give students the support and hands-on experience to flourish in those careers. From professional development opportunities to late-night study sessions, SPS and Sigma Pi Sigma show students the value and fun that comes from being part of the scientific community.

Megan Anderson, 2019 SPS National Council Executive Committee Member

SPS forms an integral and important part of my life as a physics student. It is a means through which I am more involved in the physics community and feel included in it. It also provides me with opportunities to prosper as a physicist.

Priktish Rao Suntoo, Lycoming College

I will never forget what it was like to finally feel like I had a home in SPS. College was tough, especially as a physics major, but I was able to walk into the student lounge and everyone there knew what I was going through. We were in this together and because we had each other, we were going to be alright.

Kenny S., Sigma Pi Sigma member 2002

I became a Sigma Pi Sigma member as a junior back in 1970 at St. Joseph's College (now University) in Philadelphia and was honored to become a member. Then, as a young professor in 1978 at the University of North Carolina Asheville, I was made advisor of the Society of Physics Students chapter. By 1980 I was chair of the department and remained SPS advisor for our chapter. I arranged for Rex Adelberger of Guilford College to preside over the ceremony that brought a Sigma Pi Sigma chapter to UNC Asheville in 1986. I remained chapter advisor for SPS and Sigma Pi Sigma until 2000. Receiving the national award for Outstanding SPS Chapter Adviser after 20 years was very special to me.

Michael Ruiz, St. Joseph's College, 1971

SPS has given me a community of like-minded physics undergraduates. It has enabled me to travel the US with this cohort to conferences, such as PhysCon, and form connections and get opportunities that would have been unreachable without their support. Just as importantly, SPS has given me the ability to develop outside of physics, in areas such as community outreach, and has made me not only a better scientist, but, I think, a better person as well!

Andrew Scherer, Cleveland State University

The Society of Physics Students chapter at my undergraduate institution provided me with a cohort of like-minded young physicists to interact with. We supported each other, found ways to give to our community, and had a sense of "team" that established, for me, the approach that I use in my career. Being inducted into Sigma Pi Sigma instilled in me a sense of pride in my individual accomplishments, which were the result of support from my department: my faculty, staff, classmates, and fellow SPS members.

William DeGraffenreid, President of Sigma Pi Sigma 2012–14, 2016 Physics Congress Planning Committee, California State Polytechnic University - Pomona, 1992

Our department has benefited greatly by embracing SPS and Sigma Pi Sigma and engaging in activities that promote the organizations. As a mentor I have been able to help create an environment that supports the missions of SPS and Sigma Pi Sigma. In turn, our students see the benefits of being part of groups that support their interest in physics through scholarship, service, and social interactions. Students who have actively engaged in the organizations now encourage others to do the same.

Blane Baker, 2022 Physics Congress Planning Committee Co-Chair, William Jewel College, 1986

SPS helped me and my peers to overcome the strong sense of isolation brought on by the pandemic. SPS events and projects brought many of us together.

Rahaf Youssef, St. Olaf College

SPS means engagement, encouragement, and above all—community. It is the space to learn and inspire simultaneously.

Giuliana Hofheins, Rhodes College, 2021

SPS and ΣΠΣ—A Home Base for Physics Students

by Betty A. Young, Professor of Physics and SPS Advisor, Santa Clara University

The SPS and ΣΠΣ chapters at Santa Clara University (SCU) provide wonderful opportunities for our students to thrive during their undergraduate years and beyond. SCU is an undergraduate, Jesuit, liberal arts institution established in 1968. The physics department offers BS degrees in physics (traditional or biophysics track) and engineering physics (EP, several tracks), typically graduating 10 to 15 students each year.

Our SPS group enjoys organizing social events, which include trivia competitions and Quiz Bowl (using a homemade Arduino buzzer control console, of course!), board game and movie nights, local trips and tours, barbecues, and other get-togethers that help to foster a warm spirit of collegiality in the department. These events enable physics majors and minors at all levels to see each other outside of classes and form strong, lasting bonds.

Our chapter also hosts or co-hosts seasonal and family-friendly events with a physics twist, such as making liquid nitrogen ice cream, setting up telescopes for public observing nights on campus, building functional(!) organic batteries with pumpkins, and many others. Perhaps most importantly, we have a dedicated SPS room in the department that serves as a much-needed home base—students can be there anytime, day or night, to study, hang out, play games, tutor, read, plan events, or commiserate about graduate school applications. This fall the department is moving to a modern new facility at SCU, and one of the highlights of relocating is knowing that it will include a dedicated SPS room that our chapter can use for years to come!

We also have an SPS journal club, quarterly alumni speaker events, and a new SPS “Physics, Explained” series of talks that encourage physics and EP students to investigate emerging areas in physics, ask questions, and share ideas in a fun and nonthreatening environment. SPS mentoring and tutoring programs at SCU give our newest majors a lifeline—a person to talk to at any time for extra support, guidance, and friendship. And as the younger SPS students gain experience and knowledge, they get to pay it forward by mentoring the classes after them.

In their senior year, SPS members who have consistently performed at the highest academic levels are inducted into ΣΠΣ. In the past five years we’ve added 28 new members to our chapter, which now includes 213 alums. This fall we’re celebrating the 50th anniversary of the SCU Physics Class of 1970 (delayed a year by COVID-19) and will host a panel featuring seven of the eight ΣΠΣ inductees from 1970. Panelists will share their diverse experiences after leaving SCU with a physics degree. Although each year we invite a few early- or mid-career alumni back to campus to discuss their paths with our SPS and Women in Physics clubs or give a colloquium, this is the first time we’ll have a large contingent of later-career alumni meet with current undergraduates.

About two-thirds of our alums go on to pursue graduate studies in fields such as physics, engineering, materials science, math, computer science, business, law, medicine, and teaching. To prepare for this, we aim to give every major the opportunity to do undergraduate physics research or an internship each year. Our majors participate in local, national, and even international physics conferences, and several have been able to do research overseas with SCU physics faculty or their colleagues. A department highlight each year is the SCU Physics Student Research Symposium, where students give a formal presentation of their research to a public audience.

We also teach every course in our robust curriculum every year. This enables physics and EP majors to establish a solid foundation and have the opportunity to take more advanced topical courses—including solid state, optics, advanced quantum mechanics, statistical mechanics, cosmology, and astrophysics—at the optimal time in their college career.

We are a tight-knit department that focuses on helping our students thrive—not just in college, but in life. SPS and ΣΠΣ are key to achieving this goal. ●

SCU SPS members make batteries from pumpkins. Photo courtesy of the SCU SPS chapter.

A Motorcycle or Bicycle as a Gyroscope (Sort of)

Part II: Bike stability and the effects of gyroscopic action

by Dwight E. Neuenschwander, Southern Nazarene University

In the Spring installment of this article, we considered how the wheels of a bicycle or motorcycle (bike) make the machines a kind of gyroscope. We also examined how the two spinning wheels are not as essential to the bike's stability as we might think, and we examined the importance of the castor, the distance between the steering axis–ground intersection and the front tire's ground contact point, in stability. Recall that the castor is denoted δ (Fig. 2).

Figure 2 (from part I): Showing the castor distance on a 1994 Kawasaki Vulcan (top) and a 1962 J.C. Higgins Flightliner (bottom). Their front wheels have been deliberately set straight ahead. All photos and images by Dwight E. Neuenschwander unless otherwise noted.

Now let us review the essential dimensions that concern us. Recall that Fig. 4 shows a schematic: a denotes the bike's wheelbase; Z is the point on the ground directly below the CM with the bike upright; b denotes the distance between Z and the rear tire's contact point with the ground; h is the height of the CM above the ground; and the castor distance δ is shown with an idealized vertical steering axis.

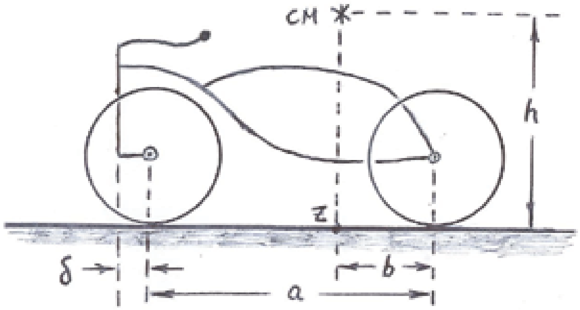


Figure 4 (from part I): View of bike from the side, showing the distances a, b, h, and δ.

We then considered the bike moving through a turn, its path the arc of a circle of radius R. From Fig. 5a, an overhead view of the bike, we let α be the angle relative to the bike frame through which the front wheel is turned; let η be the angle relative to an arbitrary fixed direction through which the frame has turned as the bike moves along the arc; and let $\hat{n}$ denote a unit vector normal to the bike's frame and pointing towards the center of curvature of the circular arc. From Fig. 5b, a view of the bike from behind it, we let θ be the lean angle of the bike from the vertical. For dynamic variables we let m denote the mass of the bike and rider, and g the magnitude of the gravitational field.

Now let's move on to consider bike stability and the effects of gyroscopic action.

On Stability

As discussed in Part I, Newton's second law in rotational form says that net torque about the steering axis on the handlebars-fork-front wheel system—torques due to lean and friction—produces a change in the vertical component of angular momentum according to

$$\frac{mb\delta}{a}\left(g\theta - \frac{v^2\alpha}{a}\right) = \frac{d}{dt}\left(I_f\dot{\alpha} - I_o\omega \sin \sin \theta\right) \quad (22)$$

where I_f denotes the moment of inertia of the handlebar-fork-front wheel assembly and I_o denotes the front wheel's moment of inertia about its axle with ω the wheel's angular velocity.

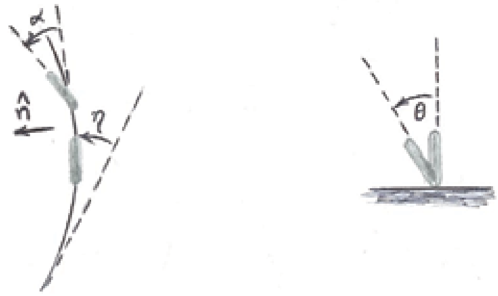


Figure 5 (from part I): View of bike from above, showing angles α and η and the unit vector $\hat{\boldsymbol{n}}$ (left). View of bike from behind it, showing the angle θ (right).

Let us return to Eq. (22) and include the front wheel's moment of inertia about its axle. With $\sin\theta \approx \theta$ and noting that $\omega = v/r$ where r denotes the front wheel's outer radius, Eq. (22) becomes

$$\ddot{\alpha} - \mu\left(\theta - \frac{v^2}{ga}\alpha\right) - \gamma v\dot{\theta} = 0 \quad (25)$$

where we have defined a gyroscopic factor γ

$$\gamma \equiv I_o/I_f\, r \qquad (26)$$

and a castor factor

$$\mu \equiv mgb\delta/aI_f\,. \qquad (27)$$

Suppose the bike travels straight and upright initially, where $\alpha = 0$ and $\theta = 0$. If at some moment $\dot{\theta}$ becomes nonzero (while α and θ are still approximately zero) then by Eq. (25) it follows that $\ddot{\alpha} \neq 0$ and the bike turns in the direction of the lean *because* of the gyroscopic effect, $\gamma \neq 0$. Let us also recall Eq. (10) from Part I, which gives the component of the gravitational force in the $\hat{\boldsymbol{n}}$ direction. Assuming θ to be small and neglecting friction, the $\hat{\boldsymbol{n}}$ component of Newton's Second Law says, with some rearrangement from (10):

$$\ddot{\theta} - \frac{g}{h}\left(\theta - \frac{v^2}{ga}\alpha\right) + \frac{bv}{ha}\dot{\alpha} = 0. \quad (28)$$

Eqs. (25) and (28), which reveal dynamic coupling between α and θ, will be our working equations in the considerations that follow.

Since Jones's experiments with modified bicycles show that gyroscopic effects are not dominant factors for bike stability, let us examine bike stability in the extreme case of $\gamma = 0$, which will be followed by the $\gamma \neq 0$ case in order to see how large a role the gyroscopic factor *does* play.

Case 1: $\gamma = 0$

With zero gyroscopic effects Eq. (25) becomes

$$\ddot{\alpha} = \mu\left(\theta - \frac{v^2}{ga}\alpha\right). \qquad (29)$$

Being proportional to the weight of bike and rider, μ is typically quite large. Consequently, if $\theta - \frac{v^2\alpha}{ga} > 0$ (e.g., the rider leans with the front wheel initially pointed straight ahead) then α grows until $\theta - \frac{v^2\alpha}{ga} = 0$. Because $\theta - \frac{v^2\alpha}{ga}$ will eventually become zero, let us assume

$$\theta = \frac{v^2}{ga}\alpha. \qquad (30)$$

With this constraint used in Eq. (28) the equation of motion for θ reduces to

$$\ddot{\theta} + \kappa\dot{\theta} = 0 \qquad (31)$$

where

$$\kappa \equiv bg/hv. \qquad (32)$$

Denoting the initial lean angular velocity as $\dot{\theta}(0) = W_o$, Eq. (31) integrates to

$$\theta(t) = \frac{W_o}{\kappa}\left(1 - e^{-\kappa t}\right) \qquad (33)$$

from which we obtain the asymptotic lean angle

$$\theta(\infty) = W_o/\kappa. \qquad (34)$$

Therefore, by Eqs. (30) and (32),

$$\alpha(\infty) = W_o ha/bv. \qquad (35)$$

Note that $\theta(\infty)$ and $\alpha(\infty)$ have the same sign—the front wheel turns in the direction of the lean. The leaning bike stabilizes itself by moving in a circular path of some radius R. To determine R, when the bike has traveled a distance along the circular arc equal to its wheelbase a, the bike frame has rotated through the angle $\alpha = \frac{a}{R}$ (see Eq. 6 in part 1), which by Eq. (35) gives for the circle's radius

$$R = \frac{bv}{hW_o}. \qquad (36)$$

All of this occurs by assuming $\gamma = 0$, i.e., with *no gyroscopic help whatsoever* from the wheels! Clearly the gyroscopic action is not *essential* for turning a motorcycle or a bicycle.

While still in the $\gamma = 0$ case, let us lift the restriction of Eq. (30) and allow $\theta - \frac{v^2}{ga}\alpha \neq 0$. Eq. (25) now becomes

$$\ddot{\alpha} + \frac{\mu v^2}{ga}\alpha = \mu\theta. \qquad (37)$$

This resembles the equation of a driven undamped harmonic oscillator. According to Eq. (37), if the handlebars are turned at a moment when θ passes through zero, then at that moment the front wheel may begin oscillating, because Eq. (37) then describes a simple harmonic oscillator. In that event we have

$$\alpha(t) \approx \alpha_o \cos(\omega t) \qquad (38)$$

with angular frequency ω,

$$\omega = \sqrt{\frac{\mu v^2}{ga}}. \qquad (39)$$

Lowell and McKell tabulate the necessary parameters for a particular bicycle (model not given) and rider.[2] For instance, their bike had $a = 1.0$ m, $b = 0.33$ m, $h = 1.5$ m, $r = 0.33$ m, $m = 80$ kg. They cite $\mu = 133\ s^{-2}$, and mention in their acknowledgments that this "Jones couple" was "rather tricky" to measure, I presume because of I_f. Their bicycle data predicts an oscillation frequency $\frac{\omega}{2\pi} \approx 2$ Hz at $v = 3.5$ m/s—low enough for an alert rider to easily make necessary corrections. But the existence of these oscillations opens the door to the possibility of a runaway oscillation, the notorious speed wobble that cyclists (especially racers) encounter in some circumstances.

How does the front wheel's oscillation affect the lean angle θ? Eq. (28), repeated here with some rearrangement, says

$$\ddot{\theta} - \frac{g}{h}\theta = -\frac{v}{ha}(v\alpha + b\dot{\alpha}) \qquad (40)$$

where h is the CM height, as described in part 1 of the article. When Eq. (38) holds and α is oscillatory, then we expect θ to also be oscillatory but possibly phase-shifted from α, because if Eq. (38) holds then Eq. (40) becomes, within a phase factor,

$$\ddot{\theta} - \frac{g}{h}\theta \approx -\frac{v\alpha_o}{ha}[v\cos(\omega t) - b\omega\sin(\omega t)]. \qquad (41)$$

The complementary solution of Eq. (41) suggests the possibility of a runaway oscillation $\theta \sim e^{+t\sqrt{\frac{g}{h}}}$ which, fortunately in most riding, does not often arise. Lowell and McKell remark,

> *"To summarize, if gyroscopic effects are ignored, the bicycle is almost self-stable. A perturbation tending to push it over results, in the first approximation, merely in the bicycle entering a curved path. However, the bicycle is unstable in the sense that oscillations in α tend to grow. In practice, the oscillatory instability would probably not matter; growth is very slow and it is possible that the oscillations would not be noticeable if the rider were anything other than completely inert."* [2]

Though not *essential* to stability, do gyroscopic effects *contribute* to stability, perhaps to damp out front wheel oscillations? Gyroscopic effects have, surely, *some* effect. Let us probe further by allowing γ to be nonzero.

Case 2: $\gamma \neq 0$

Let us return to Eq. (25) with $\gamma \neq 0$. Because the rider does not normally *suddenly* jerk the handlebars to a large angle (doing so would be disastrous), $\ddot{\alpha}$ is very small; let us approximate it as $\ddot{\alpha} = 0$, and allow that $\theta - \frac{v^2}{ga}\alpha \neq 0$. Now Eq. (25) may be written

$$\alpha = \frac{ga}{v^2}\left(\theta + \frac{\gamma v}{\mu}\dot{\theta}\right). \qquad (42)$$

Differentiating with respect to time yields:

$$\dot{\alpha} = \frac{ga}{v^2}\left(\dot{\theta} + \frac{\gamma v}{\mu}\ddot{\theta}\right). \qquad (43)$$

Insert Eqs. (42) and (43) for α and $\dot{\alpha}$ into Eq. (28), which becomes

$$\ddot{\theta}\left(1+\frac{\gamma bg}{h\mu}\right)+\frac{gb}{hv}\left(1+\frac{\gamma v^2}{\mu b}\right)\dot{\theta}=0. \quad (44)$$

Eq. (44) integrates to

$$\theta(t)=\frac{W_o}{\kappa'}\left(1-e^{-\kappa' t}\right) \qquad (45)$$

where, in terms of the κ of Eq. (32),

$$\kappa'=\kappa\left(\frac{1+\frac{\gamma v^2}{\mu b}}{1+\frac{\gamma bg}{h\mu}}\right)\equiv\kappa\zeta. \quad (46)$$

Notice that $\kappa'=\kappa$ when $\gamma=0$. If $\zeta>1$ then θ damps to its asymptotic value faster than it does with $\gamma=0$, which means gyroscopic effects *enhance* stability. In Eq. (46) ζ exceeds 1 if $\frac{\gamma v^2}{\mu b}>\frac{\gamma bg}{h\mu}$, or $v>b\sqrt{g/h}$. This inequality is satisfied for $v>1$ m/s for the bicycle parameters cited by Lowell & McKell,[2] a minimum velocity easily attained. But if $\zeta<1$, i.e., if $v<b\sqrt{g/h}$, then the oscillations damp more slowly than they would if $\gamma=0$.

Turning to the effect of γ on oscillations when $\ddot{\alpha}$ is not negligible, let us recall our working equations for $\ddot{\alpha}$ and $\ddot{\theta}$, Eqs. (25) and (28), repeated here for convenience:

$$\ddot{\alpha}+\omega^2\alpha=\mu\theta+\gamma v\dot{\theta} \qquad (47)$$

where ω^2 is given by Eq. (39), and

$$\ddot{\theta}-\frac{g}{h}\theta=-\frac{v}{ha}(v\alpha+b\dot{\alpha}). \quad (48)$$

If it were not for some contrasting minus signs, it would appear that α and θ are proportional and in phase for all situations in which Eqs. (47) and (48) apply. But despite differing signs, in the complementary solutions of these differential equations (when the right-hand sides are zero) we see intimations of a runaway oscillation: α could be oscillatory, $\alpha_c\sim\cos(\omega t)$, and θ could be exponential, $\theta_c\sim e^{\pm t\sqrt{\frac{g}{h}}}$.

Lowell and McKale carried out numerical solutions of Eqs. (47) and (48). They presented their results in graphs of θ vs. t; qualitative schematic sketches of them are shown in Fig. 10. The dotted curves include no gyroscopic effects ($\gamma=0$) and the solid curves consider nonzero γ; the red curves are for a faster speed than the black curves. These authors note that "Gyroscopic action is stabilizing in the sense that it results in a smaller (mean) value of θ, but destabilizing in the sense that it enhances the oscillatory instability."[2]

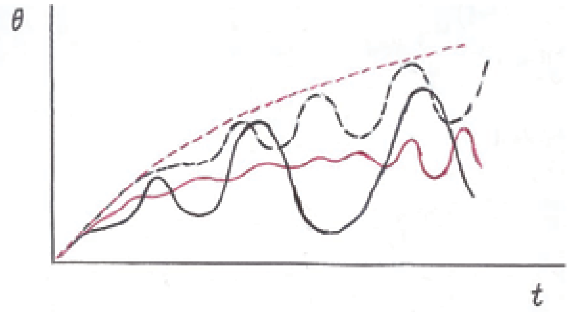


Figure 10: Schematic of data from Fig. 3 of Ref. 2 showing $\theta(t)$ for red (fast) and black (slow) velocities. The dotted curves have $\gamma=0$ and the solid curves have $\gamma\neq0$.

Let us see if we can extract an analytic approximation to this behavior. Write Eq. (47) as

$$\ddot{\alpha}-\gamma v\dot{\theta}+\omega^2\alpha=\mu\theta. \qquad (49)$$

Figure 1 (from part I): Jared Mees and his Indian Scout FTR 750 motorcycle in a controlled power slide during a flat-track race. Photo courtesy of David Hoenig, Flat Trak Fotos.

Consider a bike coming out of a left turn. During a normal left turn the bike leans to the left and the front wheel turns to the left, so that $\theta>0$ and $\alpha>0$. In coming out of the normal turn, θ and α both decrease to zero, so $\dot{\theta}<0$ and $\dot{\alpha}<0$. When the turn is completed, the bike goes straight and both angles have returned smoothly to zero (if there are no overshoots and oscillations). But in a controlled power slide like the one shown in Fig. 1, during the slide $\theta>0$ (leaning to the left) but $\alpha<0$ (front wheel turned to the right). In coming out of the slide and heading down the straightaway, the rider returns both angles back to zero. Thus $\dot{\theta}<0$ but $\dot{\alpha}>0$. To consider both cases of straightening the bike up when coming out of a turn—a normal turn or a power slide—it may be reasonable to assume that, within a phase shift,

$$\dot{\theta} = \pm k\dot{\alpha} \qquad (50)$$

for some $k > 0$. As the bike approaches $\theta \approx 0$ Eq. (49) becomes

$$\ddot{\alpha} \mp 2\beta\dot{\alpha} + \omega^2\alpha = 0 \qquad (51)$$

where

$$\beta \equiv k\gamma v/2. \qquad (52)$$

Parameterizing the solution as $\alpha(t) \sim e^{\sigma t}$ for some constant σ turns Eq. (51) into

$$\sigma^2 \mp 2\beta\sigma + \omega^2 = 0 \qquad (53)$$

and solving for σ gives

$$\alpha(t) \sim e^{\pm\beta t}\exp(\mp t\sqrt{\beta^2 - \omega^2}). \quad (54)$$

If $\beta^2 < \omega^2$, i.e. if $k\gamma v < \omega$, then $\sqrt{\beta^2 - \omega^2}$ becomes imaginary which makes $\exp(\mp t\sqrt{\beta^2 - \omega^2})$ sinusoidal, and in that case

$$\alpha(t) \sim e^{\pm\beta t}\cos(t\sqrt{\omega^2 - \beta^2}) \qquad (55)$$

which includes both possibilities of damped or runaway oscillations. By Eq. (50) a similar result holds for θ.

Having experienced a speed wobble or two myself (though not as spectacular as Don Castro's) here is my hypothesis on what may be happening in a speed wobble. As the rider comes out of the slide with θ and α approaching zero, if both angles overshoot their zeroes the rider may for a moment be leaning to the right with the front wheel pointing to the left. Of course, in any riding situation the rider makes corrections continually, but if the overshoots of θ and α are not sufficiently small, some combination of parameters can lead very quickly to an exponentially growing speed wobble (the + sign in the exponential of Eq. 54).

Tire shape also has an important effect on bike steering and stability. The cross-section of a car tire is approximately horizontal where it touches the road. But because a bike leans over in turns, the cross-sections of motorcycle and bicycle tires are rounded. Thus during the lean significant tire surface still contacts the road, contact so necessary for maintaining the frictional force between tire and road. In addition, the tires of a car or non-leaning bike roll like cylinders, but when a bike leans its tires behave more like rolling cones (Fig. 11)[1]—the trajectory turns in the direction of the cone's smaller end.

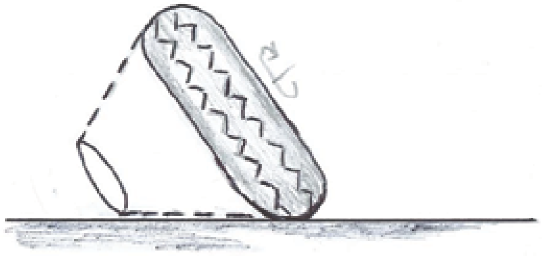


Figure. 11: Because of its rounded cross-section, a rolling leaning tire behaves like a cone, helping the bike turn.

When riding a bicycle or motorcycle, one must pay sharp attention to other traffic, road conditions, and being visible (assume you are invisible). However, when traffic is minimal and there are no woods next to the road that might conceal foraging deer, you can meditate on some interesting physics of the stability and steering of bikes. Ride safe! •

Figure 12: When leaning on the kickstand a bike's front wheel turns into the lean, as illustrated with a 2006 Yamaha Royal Star Midnight Venture near Pie Town, New Mexico.

Acknowledgment
I thank David Hoenig and Kathy Hoenig of Flat Trak Fotos for graciously granting permission to use the photo in Fig. 1.

This article offers a drastic revision of the Summer 2003 *Radiations* Elegant Connections article, which was ridiculously over-simplified.

Part I of this revised article is available on the *Radiations* website, *www.sigmapisigma.org/sigmapisigma/radiations/spring/2021/motorcycle-or-bicycle-gyroscope-sort.*

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[7] In countersteering for a left turn, one can push the left handlebar forward, or pull the right handlebar backward, or both. Either way produces a clockwise initial torque, which is overcome by the counterclockwise torque due to sideways friction on the tire. For a right turn, push the right handlebar forward and/or pull the left handlebar backwards. These are very subtle gentle pushes, not yanks, but the response is immediate.

Spotlight on Hidden Physicists

The Consultant, Elizabeth Hook-Rogers

Senior Consultant with Booz Allen Hamilton

Elizabeth Hook-Rogers. Photo courtesy of Hook-Rogers.

I graduated from Rhodes College in 2011 with a bachelor's in physics and am now a senior consultant with Booz Allen Hamilton. I support the Earth Science Division onsite at NASA Headquarters in Washington, DC, where I live with my wife and our cat, Wallace.

When I went to college, I planned to be a history major, but I also joined my school's SPS chapter. One of the Rhodes physics professors noticed my interest and how much I loved doing outreach, and she helped convince me to become a physics major. Since then I've worked in science programs and science communication (including for SPS!).

Today, in my role as senior consultant, I'm a High-End Computing (HEC) Program support lead and Research and Analysis (R&A) Program support scientist. I split my time evenly between the two programs. In my work for R&A, I keep track of many of NASA's activities with other federal agencies, as well as international activities. As an example, when the International Panel on Climate Change drafts climate reports, the group often asks for NASA comments. My job is to contact our expert researchers to see if they have comments, then pass them along. My role in the HEC program is to support the program manager. This can involve attending meetings and taking notes, helping to keep track of special projects and coordinating with the internal teams supporting them, and helping to draft strategic plans for the program.

The job can be challenging because I work with a lot of people, and when you collaborate with someone, it's important to learn their communication style to be most effective. It takes a little bit of time, but especially for every new project, it's worth figuring out. I also spend a good amount of time in meetings, which can make it hard to get work done! My colleagues are required to be at a lot of meetings too, so even if I'm not attending one, I might need something from someone who is.

My job can be fast-paced at times and can also take a lot of focus. In earth science we're dealing with climate change on a daily basis, and sometimes the science results we see and work with can be overwhelming. It's important to me to balance work and relaxation. I love living in DC. There's so much to do and so many great restaurants and people. In non-COVID times, I've also loved going to musical theater performances; we have a thriving theater scene here. I'm originally from Nashville, Tennessee, which has a very different vibe from DC, and I like living in a city that's bigger but not too big.

Throughout my career, I've also been involved with LGBTQ+ employee resource groups, and I'm passionate about inspiring women and girls to pursue their interests in STEM. I've made it a priority to participate in mentoring opportunities with students from middle school to college. I've participated in Adopt-a-Physicist, and I've also been a pen pal and have had coffees and meetings with interns at NASA.

My advice to undergraduate physicists: You don't have to go to graduate school immediately (or ever!). I didn't, and I've found being in the workforce to be truly valuable and enjoyable. The structure of school (including academia) just isn't how I learn best, and that's okay. School is extremely important, but it isn't the be-all–end-all. ●

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Radiations
American Institute of Physics
1 Physics Ellipse
College Park, MD 20740