

The **SPS Observer**

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Einstein Addressing Racism

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Music Inspired by Astronomy *(Page 8)*

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Einstein as Citizen: Addressing Race and Racism

By Fred Jerome and Rodger Taylor
Co-authors of *Einstein on Race and Racism*
(Rutgers University Press, 2006)
Adapted from a plenary speech at the 2008
Sigma Pi Sigma Congress

In 1946, more than a million African American GIs were returning home from World War II where they had played a crucial role in helping to defeat Hitler and destroying fascism in Germany and Japan. Most of these black GIs were returning to homes in the southern States, where unfortunately Jim Crow fascism still ruled. A new wave of lynchings spread across America at that time. In the very first year after the end of the War, some 56 black men and women were lynched in this country, mostly in the South and mostly black GIs returning home. At first there was not much news coverage, but in July the *New York Times* carried this story on their front page:

GEORGIA MOB OF 20 MEN MASSACRES
2 NEGROES, WIVES; ONE WAS EX-GI

MONROE, Ga., July 26 — *Two young Negroes, one a veteran just returned from the war, and their wives were lined up last night near a secluded road and shot dead by an unmasked band of twenty white men...*

The Negro men were taken out of the car first and led down a side road. The women were held at the automobile. Then a member of the mob said that one of the women had recognized him. Several of the men then...dragged the shrieking women from the automobile....

The story also reported that the victims had been shot at least sixty times, and the bodies were "scarcely recognizable" because of the large number of bullet holes.

Like millions of other Americans, Albert Einstein read that morning about the lynching. He could have made a speech denouncing lynching. Since he was Einstein, his speeches were publicized. But Einstein felt that words were simply not enough to deal with this awful racism. So he joined Paul Robeson as co-Chairman of a new organization: The American Crusade to End Lynching. They organized a demonstration in Washington, DC, demanding that Congress make lynching a federal crime. They had a confrontation in the White House with President Harry Truman. [Einstein was too ill to attend the demonstration, but he sent a letter with Robeson



Lincoln University President Dr. Horace Mann Bond awards an honorary degree to Albert Einstein on the occasion of the Conference on Objectives, May 3, 1946, at which Einstein announced that he would "not remain quiet" about segregation.

Photo courtesy of Lincoln University of Pennsylvania, Special Collections and Archives, Langston Hughes Memorial Library

for President Truman....the letter was published in the *New York Times*....but Truman said "The time is not right.]"

In many ways, the Robeson/Einstein-organized demonstration was the forerunner of the civil rights movement that began sixteen years later.

James Baldwin wrote, "If history were past, history wouldn't matter. History is the present... You and I are history. We carry our history. We act our history." It has only been through writing our book, *Einstein on Race and Racism*, and then talking to folks about it—traveling all over the country to talk with folks—that we have come to understand what James Baldwin meant when he said "We are our history....we live our history."

You see, we thought we were writing about long ago historylast century history.... Albert Einstein and W.E.B. Du Bois and Paul Robeson ...famous people all (although Robeson and Du Bois were not nearly as famous as we'd thought), famous people, but not today's people — history people. But we discovered that in writing about the struggle against racism—or shall we say that writing about anti-racism in America—we were writing about today!

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Albert Einstein discusses relativity with students at Lincoln University of Pennsylvania during his 1946 visit.

Photo courtesy Lincoln University of Pennsylvania, Special Collections and Archives, Langston Hughes Memorial Library



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Authors Rodger Taylor, second from left, and Fred Jerome, second from right, speak with Chicago State University students Erica Watkins, Melissa Rangel, and Chaan Thomas after their presentation to the 2008 SPS Congress.
Photo by Sean Gallardo

So, our path through the history of today starts here with a little game of “Concentration”—you know, if I say “ice,” you say “cold,” and so forth. So, if I say “Einstein,” what word or phrase comes to your mind? Perhaps “genius,” “ $E = mc^2$,” “Relativity...” It’s almost universal. We have tried this again and again, and the age, sex, race, or background of our respondents do not seem to matter. Everybody says the same thing (some say “the hair!”). But very few people will say “social activist,” and virtually no one says “anti-racist.” When we point out Einstein’s stands against racism, people say “I had no idea!” How many times have we heard those words, said those words, and FELT those words while working on this book!

In the numerous biographies written about Einstein, amid the many topics covered that range from his love letters to the adventures of his brain after his passing, not one biography explores, and few even mention, Einstein’s fight against racism.

Albert Einstein was forced out of Germany when Adolf Hitler and the Nazis came to power in 1932. While growing up in Germany, Einstein was so disgusted by the militaristic nature of German society that as a teenage draft dodger he left the country and renounced his citizenship. Einstein returned to Germany many years later as a professor at the University of Berlin. As an outspoken pacifist, the world’s most brilliant scientist, and a Jew, Einstein also represented everything the Nazis hated. Had he not become a refugee he would have been arrested and killed. Thus, in the fall of 1933 Einstein ended up in scenic Princeton, New Jersey, “a banishment,” he joked, “to paradise.” But there he quickly discovered a virulent racism against African-Americans, led by one of the oldest, richest educational institutions in the country. Princeton University then did not accept black students. Its most famous president, the toxic racist Woodrow Wilson, exemplified the university’s and the area’s segregationist traditions. The great singer, actor, athlete, and activist Paul Robeson, who was born in Princeton, called the community “the northernmost town in the South”: schools,

jobs, homes, churches, and restaurants were segregated there into the late 1940s.

In direct defiance of those who ran the Princeton establishment and in solidarity with the local African Americans, Albert Einstein, the town’s most famous citizen, spent significant time walking and talking in the local African American community known as Witherspoon Street. One of the most important parts of writing this book for us was interviewing those black Princetonians who knew, and whose parents knew, Albert Einstein—people like 100+ year old Albert Hinds or Alice Satterfield, whose recollections and experiences with the great scientist were published for the first time.

We’d like to share this excerpt from our book:

In 1951, the world-renowned African American scholar, historian, and a founder of the NAACP [National Association for the Advancement of Colored People, founded in 1909], W. E. B. Du Bois was arrested by the federal government and charged with being a “foreign agent.” At the age of 83, Dr. Du Bois was brought into court, dignified as he always was in his three-piece suit and goatee, standing before the judge – short in stature but unbending – in handcuffs. Imagine the impact of the news photos that were published! It was the beginning of McCarthyism and the great Red Scare in America. Dr. Du Bois was an officer of a group called the Peace Information Center, and his so-called crime was circulating a petition, the Stockholm Peace Petition, which called for total disarmament and was signed by several million people around the world.

After the prosecution presented its case, which consisted of one paid informant, the judge turned to Du Bois’ defense attorney, a former congressman named Vito Marcantonio, to ask if the defense was ready.

Marcantonio casually told the judge, “Dr. Albert Einstein has offered to appear [first] as a character witness for Dr. Du Bois.” Judge [Matthew F.] McGuire fixed Marcantonio with a long look, and then adjourned the court for lunch. When court resumed [in the afternoon], Judge McGuire dismissed the case.

A few days later, Du Bois wrote to Einstein:

*My dear Dr. Einstein:
I write to express my deep appreciation of your generous offer to do anything that you could in the case brought against me by the Department of Justice.*

I am delighted that in the end it was not necessary to call upon you and interfere with your great work and needed leisure, but my thanks for your generous attitude is not less on that account.

*Mrs. Du Bois joins me in deep appreciation.
Very sincerely yours,
W. E. B. Du Bois*

You won’t find that story in any of the more than 100 biographies, anthologies, and

monographs about Einstein. In fact, you won’t even find the name of W.E.B. Du Bois, [exception: W. Isaacson, “*Einstein: His Life and Universe*,” p. 531, published May 2008, Jerome/Taylor published 2006] nor any mention of the American Crusade to End Lynching that Einstein and Robeson co-chaired, or the Civil Rights Congress.

Nor will you find in any Einstein biography or anthology a single word from Einstein’s speech on May 3, 1946, to the students and faculty at America’s oldest black university, Lincoln University in Pennsylvania. There Einstein declared, “Segregation is a disease not of colored people but of white people—and I do not intend to remain quiet about it.” That speech is totally missing from Einstein’s extensive archives—vanished!—gone!—until now. Were it not for its wide coverage by the black press, we would have no inkling of what Einstein said at Lincoln.

Nor will you find in any of the more than 100 Einstein biographies the name of Paul Robeson, despite the fact that Einstein and Robeson had a friendship that spanned 20 years. You cannot understand the depth of Einstein’s anti-racism without understanding his relationship with Paul Robeson. We have found a lot of folks don’t know who Robeson was, so we’d like to show a DVD about him....[here a video clip from the film *Here I Stand* by the late St. Clair Bourne was shown to the audience].

During the 1940s, Robeson’s civil rights and anti-colonialist activities brought him to the attention of Senator Joseph McCarthy. Despite his contributions during World War II, Robeson was singled out as a major threat to American democracy. Every attempt was made to silence and discredit him, and in the 1950s the persecution reached a climax when his passport was revoked. When he could no longer travel abroad to perform [he had a tremendous following across Europe, Africa, and Asia], his career was stifled. To this day, Paul Robeson’s many accomplishments remain under attack by the propaganda of those who tirelessly dogged him throughout his life.

But let us come back to why this is about today. The first thing that happened after we wrote the book was that virtually none of the mainstream media thought it was important enough to write about. One publication—*Publishers Weekly*—even said so. They said “Einstein was a man concerned about race...so what?”

And the *New York Times*...well, the *New York Times* made it quite clear. We got a terrific review from them but it was published in the New Jersey edition only, which has a circulation of about 34 people. (I might mention how the *New York Times* took Robeson’s name out of my op-ed piece six years ago—F. Jerome).

Racism has been the 800-pound gorilla in the room that no one seems to notice or talk about. Even in the recent campaign in which the first African American ever has become president, part of Obama’s strategy was to not talk about racism. Sixty years ago Einstein wrote in a message to the Urban League’s 1946 National Convention that “the taboo, the ‘let’s-not-talk-

Some Glimpses of Albert Einstein's Anti-Racism[1,2]

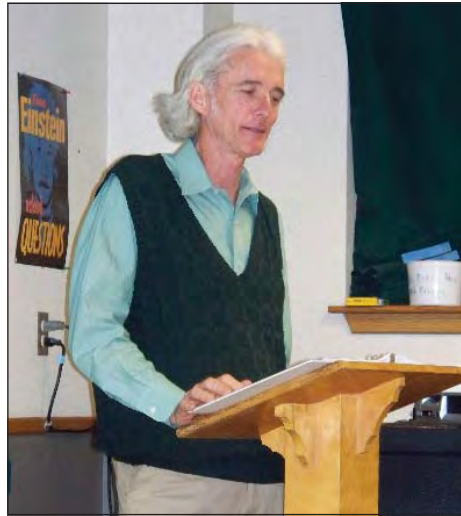
Albert Einstein arrived at Princeton, New Jersey, in October 1933 to assume his position at the newly founded Institute for Advanced Study, adjacent to but independent of Princeton University. He came as a Jewish refugee from Nazi brutality. Founded in 1746, the University has a distinguished academic history, but in those days there was in Princeton a culture of racial discrimination that echoed what Einstein had just fled. From the time of the University's sixth president, John Witherspoon, the college had carefully cultivated relationships with southern elite. In the 1840s over 40% of its students were from the South; that fraction reached 51% in 1848. [3] In *Einstein on Race and Racism* Fred Jerome and Rodger Taylor describe how "Wealthy, white, and southern, Princeton students created more-than-usual tension, grief, and terror for the town's African American population. At one point early in the twentieth century, the black community even set up a curfew to protect its children." [4] One member of the class of 1928 had remarked, "Princeton is popular through the South because it is one eastern school which does not enroll Negroes." [5]

Jerome and Taylor remark how Einstein "only had to walk a few blocks down Witherspoon Street to be reminded of how fleeting freedom could be." [6] Witherspoon Street went through Princeton's black community, and Einstein walked there frequently. Here are recollections, gathered in interviews with Jerome and Taylor, of some individuals from Witherspoon Street who lived there at that time, who carry personal recollections of their encounters with Einstein:

From Lloyd Banks: "*Einstein was unusual for a white person to a degree—he wasn't bothered being in the black community. We would run out—as children we always ran out and talked to him and he would stop and talk to us. We would be shouting 'Dr. Einstein, Dr. Einstein'—and he would stop and take a few minutes*

Einstein, continued from page 3 about-it' must be broken. It must be pointed out time and again that the exclusion of a large part of the colored population from active civil rights by the common practices is a slap in the face of the Constitution of the nation." In the same message Einstein called racism "America's worst disease."

The recent presidential election has in many ways changed, or has created the opportunity to change, that dynamic. But it echoes today, even as we had an African American running for President, there was still a strange silence about racism:



Dr. D. E. Neuenschwander, speaks to the recent SPS meeting in Zone 12 on "Taking Einstein's Ethics into the Twenty-First Century."

Photo submitted by East Central University, Ada, OK

with us. He took the time to talk to us. He was very friendly. It seems as though it was almost every day, or at least every week." [7]

From Alice Satterfield: "*I worked in the kitchen at the Institute for Advanced Study... and got to know Einstein. If I didn't get the bus and Professor Einstein would be walking, we'd walk together until we got to his residence. I'd bid him good-bye and continue home. We didn't talk a lot—on a couple of occasions he held my hand without saying anything. He would just walk in a silent and wonderful way in which you knew everything would be all right. You felt good walking with him. He did not look down on people. He was inspirational.*" [8]

From Henry Pannell: "*I guess everybody my age in this community remembers seeing Einstein when we were kids. He'd come by—white sneakers, no socks, a loose-fitting sweater—and he'd give nickels to us kids. I remember him coming up and sitting on my grandmother's*

porch and chatting with her...Einstein used to talk to everybody in our community. He didn't just come and sit on my grandmother's porch, but on the Wilsons' porch and others. He'd talk with everyone." [9]

From Rod Pannell: "*...He was almost like a part of the community.*" [10]

Einstein came by these associations naturally. Back in 1931, when he was living in Berlin, at the request of Dr. W.E.B. Du Bois, founder of the NAACP and editor of its magazine *The Crisis*, Einstein offered a short essay on the evils of racial prejudice. Einstein noted how the victims of racial prejudice too often buy into their own diminishment. He wrote,

"This second and more important aspect of the evil can be met through...conscious educational enlightenment of the minority, and so an emancipation of the soul of the minority be attained. The determined effort of the American Negroes in this direction deserves every recognition and assistance." [11]

Twenty years later when the federal government indicted the 83-year-old Du Bois during the McCarthy madness, Einstein offered himself as a character witness on Du Bois' behalf—the Jerome and Taylor feature article describes the result of Einstein's offer during those troubled times. [12]

In 1937 the renowned concert singer Marian Anderson came to Princeton to perform but was denied accommodation at the whites-only Nassau Inn. So Einstein promptly invited her to stay as his guest in his home, which she did many times over the years. [13] Einstein also became a close friend of the great Rutgers athlete, Shakespearean actor, baritone, lawyer, scholar, and human rights activist Paul Robeson. From their first meeting backstage at the McCarter Theatre in 1935 they found much in common, such as their active opposition to fascism. Following a wave of lynchings in the summer of 1946 that for once made the news, Robeson founded, and he

* 33% of white Democrats said they won't vote for a black candidate;

*As recently as October 4, 2008, in a front-page story the *New York Times* reported unemployment among white Americans at 5.4%, and unemployment among black Americans at 11.4%;

* Not to mention inequities in housing, health, and education.

And during the recent election the socialist baiting of Barack Obama also chillingly echoed the 1950s (don't forget that Robeson, Du Bois, and Einstein all called themselves socialists). The very election of Obama will have a significant effect, even if it's just symbolic: minorities

will feel empowered, and the world will look at the U.S. differently. Children of all types will have a better self image.

But we can't settle for symbolic victories when fighting racism—we must have tangible change. More than 50 years ago, right after the 1952 elections, Paul Robeson wrote "The average income of black Americans is 54% of the income of white Americans. The elections are over but the struggle for equal rights goes on, and must go on harder than ever before." Einstein agreed with Robeson that it was true then, and clearly they both would agree that it is just as true today.

—Fred Jerome and Rodger Taylor

and Einstein co-chaired, the American Crusade to End Lynching.[14] In those days, to be for civil rights was to be labeled a Communist, and the FBI collected a thick dossier on Einstein's so-called subversive activities. With its lack of source-checking and excluding evidence that refuted collected statements, the file tells more about J. Edgar Hoover's Red-baiting, and his lack of respect for the Constitution, than it does about Einstein.[15]

After he had lived in the USA for thirteen years, Einstein could remain silent no longer on American racial discrimination. He published in the January 1946 issue of *Pageant* magazine the article described below. It illustrates how he brought to the analysis of ethical problems the same clarity of thought that he brought to relativity and the quantum. Sometimes there is value in *thinking like a physicist*, even when the problem lies outside the scope of physics.

So let us digress to recall Einstein's celebrated five papers of 1905. One paper demonstrated how the concept of quantized light must be taken seriously. Two closely related papers showed how Brownian motion could tell us whether molecules are real and yield a measure of their size. A fourth paper introduced special relativity. The fifth showed the equivalence of mass and energy. In these papers we can identify six practices in Einstein's approach to doing physics:[16]

1. *Einstein questioned assumptions that others took for granted.* For example, the paper on light quanta began by asking why matter was conceptualized as discrete particles but the electromagnetic field as continuous.

2. *Einstein worked always from first principles.* He motivated light quanta by going back to the second law of thermodynamics, comparing the entropy of radiation to that of a gas of particles.

3. *Einstein pursued ideas relentlessly to their conclusions.* $E = mc^2$ was a logical consequence of the relativity paper.

4. *Einstein worked not from ideology but from his understanding of reality.* He did not create special relativity by defending some philosophical position on whether space and time are absolute or relative; rather, he asked how one *actually measures* the time interval between separated events, and the length of a moving object.

5. *Einstein demanded that all claims be tested in reality.* In the mass-energy equivalence paper he suggested how the theory could be tested with radium.

6. *Above all, Einstein possessed an inner freedom.* This personal quality made everything else possible.

These values for doing physics are seen in Einstein's 1946 article on American racial discrimination.[17] He began by recalling an assumption enshrined in American ideals:

...In the United States everyone feels assured of his worth as an individual. No one humbles himself before another person or class...

Next the physicist who in 1905 wrote of electrodynamics that "there seem to be asymmetries not inherent in the phenomena" noted an inconsistency between American ideals and practice:

There is, however, a somber point in the social outlook of Americans. Their sense of equality and human dignity is mainly limited to men of white skins...The more I feel an American, the more this situation pains me. I can escape the feeling of complicity only by speaking out.

Einstein mentions the unexamined assumption of intrinsic racial inequality that was held by many Americans at the time. He proceeds to smash this assumption with the realities of history:

I am firmly convinced that whoever believes this suffers from a fatal misconception. Your ancestors dragged these black people from their homes by force; and in the white man's quest for wealth and an easy life they have been ruthlessly suppressed and exploited, degraded into slavery. The modern prejudice against [blacks] is the result of the desire to maintain this unworthy condition.

Einstein next reminds us how even the most intelligent members of society can buy into its contradictions:

The ancient Greeks also had slaves. They were [not blacks but] white men who had been taken captive in war. There could be no talk of racial differences. And yet Aristotle...declared slaves inferior beings who were justly subdued and deprived of their liberty. It is clear that he was enmeshed in a traditional prejudice from which, despite his extraordinary intellect, he could not free himself.

Now Einstein goes back to first principles and pursues their inferences, in this case, that our upbringing from childhood should be tested against reality:

A large part of our attitude towards things is conditioned by opinions and emotions which we unconsciously absorb as children...It would be foolish to despise traditions. But...we must try to recognize what in our accepted traditions is damaging to our fate and dignity—and shape our lives accordingly.

I believe that whoever tries to think things through honestly will soon recognize how unworthy and even fatal is the traditional bias against [blacks].

Finally, Einstein suggests how to implement these principles in the real world:

What...can the man of good will do to combat this deeply rooted prejudice? He must have the courage to set an example by word and deed, and must watch lest his children become influenced by this racial bias...

Einstein wrote these lines eight years before *Brown vs. Board of Education*, and nine years before the world knew the quiet courage of Rosa Parks. Perhaps such public statements by Einstein and others helped to create the climate where Rosa Parks knew that she would not be alone.

In May 1946, Einstein visited Lincoln University, near Philadelphia, to accept an honorary doctorate.[18] Founded in 1854, Lincoln University was the first institution anywhere in the world to offer higher education to youth of African descent.

During the last twenty years of his life, Einstein hardly ever spoke at universities. But he accepted the Lincoln University invitation because, as he told the assembled students and faculty, it was "in a worthwhile cause." (In case you were wondering, he did indeed deliver a talk on relativity during his visit to Lincoln University; see cover photo.) He went on to observe, "The separation of the races is not a disease of colored people, but a disease of white people, [and] I do not intend to be quiet about it."

Albert Einstein long ago earned the respect of the physics community and the wider civilization for his scientific intellect. He also deserves to be respected—and emulated—for his stand against racism. Let us "not be quiet about it" either.

--D.E. Neuenschwander

[1] F. Jerome and R. Taylor, *Einstein on Race and Racism* (Rutgers University Press, 2006).

[2] Connective narrative adapted from the 2004 Sigma Pi Sigma Congress speech, D.E. Neuenschwander, "Taking Einstein's Ethics into the Twenty-First Century," as extended in the spring of 2009 (after meeting Ref. 1 and its authors) for presentation at the Oklahoma School of Science and Mathematics and a SPS Zone 12 meeting. The 2004 version may be found in *SPS Observer* 38 (online, www.spsobserver.com), Summer 2006.

[3] Jerome & Taylor, p. 22.

[4] *ibid.*, p. 32.

[5] *ibid.*, p. 22.

[6] *ibid.*, p. 33.

[7] *ibid.*, pp. 35-36.

[8] *ibid.*, p. 44.

[9] *ibid.*, p. 41.

[10] *ibid.*, p. 36.

[11] The Du Bois-Einstein correspondence and Einstein's article for *The Crisis* are quoted in Jerome and Taylor, pp. 135-138. Einstein's *Crisis* article originally appeared in the February 1932 issue of that magazine, p. 32, and was reprinted under the heading "Minorities" in A. Einstein, *The World As I See It* (Citadel Press, a translation of *Mien Weltbild* of 1934), pp. 78-79, and *Ideas and Opinions* (Three Rivers Press, 1954, 1982), pp. 113-114.

[12] See Jerome & Taylor, Ch. 9.

[13] *ibid.*, pp. 42-43.

[14] *ibid.*, Chs. 5 and 10.

[15] *ibid.*, pp. 154-160.

[16] Ref. 2.

[17] A. Einstein, "The Negro Question," *Pageant* (Jan. 1946); reprinted in Jerome & Taylor pp. 139-142 and in A. Einstein, *Out of My Later Years* (Citadel Press, 1956, 1974), pp. 132-134. In the present article, when quoting passages of Einstein's 1946 article where he used the word "...Negroes..." I write "...[blacks]..." Here's why: If Einstein were writing about civil rights today, we have reason to believe he would use "blacks," because that seems to be the preference of African Americans themselves. Einstein would respect that, and so do I. -Ed.

[18] Jerome & Taylor, pp. 88-92.

SPS at Meetings

Our Journey through the APS March Meeting:

American Physical Society (APS) March Meeting

Pittsburgh, PA, March 16-20, 2009

By David Jacome, Ronald Maldonado, Tony Maldonado, Samik Adhikari, and Luan To, Saint Peter's College. To read the entire report, visit http://www.spsnational.org/meetings/reports/2009/aps_march_spc.pdf.

One of the biggest physics meetings ever, the APS March Meeting, started on Monday, March 16, 2009, in Pittsburgh, PA. A recorded 7,000 physicists were in attendance. The David L. Lawrence Convention Center was in the center of Pittsburgh, with its doors open to all who registered. We didn't expect to find such a beautiful city waiting for us.

Monday, March 16

On Monday, our group decided to check out some of the talks. One of the best things about this meeting was that it was open to everyone. Those who registered could explore anything of interest, go to sessions, and listen to talks on topics they found interesting. We all disagreed with each other multiple times on which talk we should go to next.



The 2009 APS March meeting was held in Pittsburgh, PA.

Photo by Ken Cole, APS

We all attended the Undergraduate Research II Session and were all happy to see SPS students presenting their research. All of the talks were very informative. Those who presented did a great job and represented the Society in the best way. Ronald Maldonado said, "I felt quite comfortable listening to the research, and most of the things mentioned were well explained and understood; it was great to be a part of that experience."

Another talk we attended was *Indirect Optical Injection of Carriers and Spin in Silicon*. We learned about generating a two-photon indirect absorption in silicon. The room was packed with people who wanted to hear the talk, and afterward many asked questions about the research. We all felt like we had picked the right place to be during this time.

Once this session concluded, we attended the awards session. David Jacome's past advisor Dr.



Ronald Maldonado (left), and David Jacome (right) with Dr. Yves Chabal. Chabal was awarded the "2009 Davisson-Germer Prize in Atomic or Surface Physics" at the meeting.

Photo by Tony Maldonado

Yves Chabal received an award for his research. David said, "It was just overwhelming to be in the room with the person who helped me tremendously in my career and see him being rewarded for all of his hard work over the years. At that moment I was proud to be a physicist."

Our evening was great. After some exploring, we took the PAT train, took a climb-car to see all of Pittsburgh, and visited some local landmarks. We met other physicists from the meeting and had some interesting conversations about the research they do in other countries.

Tuesday, March 17

On Tuesday morning we couldn't believe that the meeting wasn't over, but simply on its second day. The first talk we attended was *Optimized Vacuum Thermionic Energy Conversion Using Diamond Materials*. Joshua Smith explained the vacuum thermionic energy conversion device (TEC) and how it's an attractive alternative to other means of energy production. We asked him a lot of questions and learned a lot from his research.



Over 750 posters were presented throughout the meeting.

Photo by Ken Cole, APS

Then we split up so that we could all listen to talks of interest. Some of us joined the discussion during the talk *Nonlinear Optical Properties of Carbon Nanotubes from First Principles*. Other members of our group attended *Exploring Possible Magnet Properties of Ordered Manganese Monolayer on Wurtzite GaN*. We really took an interest in this talk. Afterward, many of us debated and argued about what was calculated. Finally, we all agreed to take a break and visit the exhibit hall and talk with a few companies about possible internship opportunities.

Many companies took an interest in us, giving us business cards and agreeing to send information by mail. The meeting was a great way to see what companies offer to students. David Jacome said, "Seeing all the companies in one place was great. Students got the chance to interact with those involved in the manufacturing process. It truly pays off in a big way to know someone."

Wednesday, March 18

It was the day for poster presentations. The poster session started at 12:00 pm and we spent three hours presenting our posters. Many students complimented our research and shared common interests. Apart from all the great posters that were seen and presented, we also took special interest in some of the research from different countries being presented at this meeting.



Luan To (left) and Tony Maldonado (right) with the poster from St. Peter's College.

Photo by David Jacome

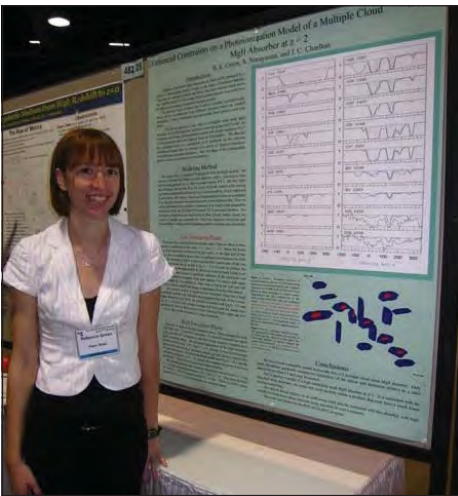
It was great to see so many faces at this meeting and the passion that many students share for physics research and outreach. At this meeting, we established good relationships with students from California, Ohio, Mexico, Texas, Florida, Pennsylvania, New Jersey, Switzerland, Germany, and other parts of the world. Each student gave us contact information to use for future collaborations and tours of their facilities.

SPS at Meetings



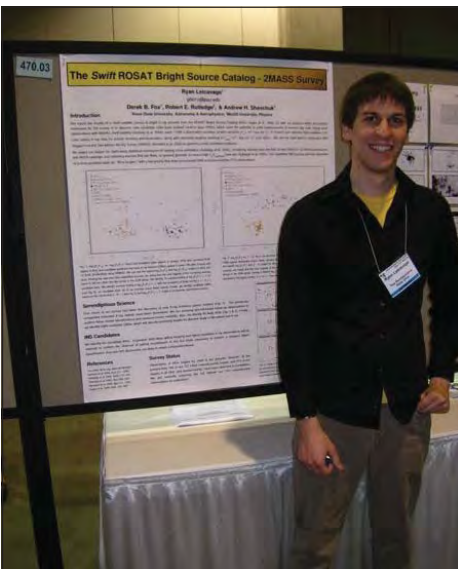
The Galileoscope™ is a high-quality, low-cost telescope kit that enables you to see the celestial wonders that Galileo first glimpsed 400 years ago. For more information, visit: <https://www.galileoscope.org/gs/>.

Photo by Rick Fienberg



Astronomy major Rebecca Green from Penn State University with the poster she presented at the AAS meeting.

Photo by Kaylan Wessels



Penn State University SPS member Ryan Letcavage also presented a poster at the AAS meeting.

Photo by Kaylan Wessels

From the Rose Bowl to Gamma-Ray Bursts:

The American Astronomical Society (AAS) 213th Meeting

Long Beach, CA, January 4-8, 2009

By Therese Jones, Penn State SPS President, College Station, PA. To read the entire report, visit http://www.spsnational.org/meetings/reports/2009/aas_winter.htm.

Having left a bit early for this year's meeting to watch Penn State in the Rose Bowl, I managed to make it to Long Beach in time to attend several of the pre-meeting workshops. Both workshops I attended were International Year of Astronomy (IYA2009) focused and were free to attend. The first, focused on *Hands-On Optics and the Galileoscope*, involved a plethora of demonstrations using lenses, lasers, UV beads, and a black light. We each received a free kit containing these items and mini-telescopes, which our chapter has already used at an elementary school science day and while teaching middle school Science Olympiad students.

The second workshop I attended was on Dark Sky Awareness; a primary goal of the International Year of Astronomy is focused on the reduction of light pollution across the globe. We used light meters to determine the amount of extraneous light emitted from different light fixtures. Campaigns in several cities have aimed to switch fixtures so that they point downward, dramatically decreasing light pollution. After our real demonstration, we were given a tour through the IYA2009 dark skies Second Life Island, where you (as Galileo) are capable of traveling around a city and exploring the light pollution that exists. Other topics that were covered in the workshop included environmental impacts of poor lighting, designated dark sky sites across the U.S., and astrophotography. The November 2008 National Geographic issue has great coverage of this topic for anyone who wants to learn more.

After the Dark Skies workshop, the conference kicked off with the undergraduate reception and opening reception. Over the past three years, I have perceived these receptions as social events to reunite with colleagues/classmates and make connections, but this year, as I was applying to graduate school, the events served as time to run around and find representatives from each graduate school I was interested in attending. Graduate schools generally send at least one representative to talk to prospective students, so it is important to complete applications prior to the meeting; that way they can find you during your poster session.

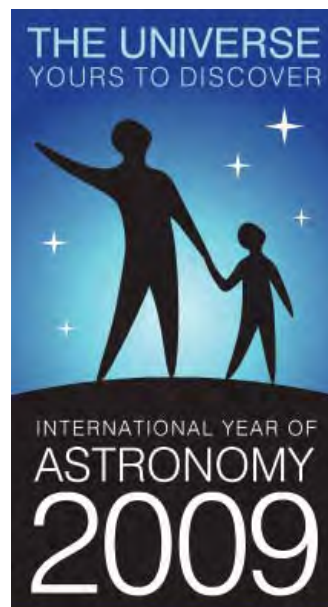
The following four days were packed with plenary talks, oral sessions, and poster sessions. I spent every day but Wednesday, my poster day, running from session to session, trying to catch as many extragalactic astronomy and cosmology talks as possible. One of the plenary sessions this year, given by Roger Blandford, was on the Decadal Survey; every ten years the Astronomical

survey, covering all areas of astronomy from research to diversity in astronomy, provides a good overview of recent research as well as the state of the profession.

I presented research on strong Mg II absorbers along quasar and gamma-ray burst (GRB) sightlines. Quasars and GRBs, as they are extremely luminous, may be used to study material between us and the quasar/GRB, as seen by absorption lines in the object's spectrum. At present, it seems that there are four times as many of these absorbers toward GRBs than toward quasars; one would not expect a difference in numbers if the absorbers were all due to random galaxies along the line of sight. I performed an analysis of the absorption profiles of the absorbers in the two different categories in an attempt to determine if the difference in numbers was due to material in the GRB host galaxy but found that it was impossible to distinguish between the quasar and GRB absorption profiles, suggesting that the excess is not due to GRB host galaxy gas. The cause of this difference is still unknown, although some light may be shed on the issue via imaging of the GRB fields.

The people who I encounter at the meeting never cease to amaze me; the final meeting highlight was seeing Neil deGrasse Tyson break out his dancing moves on the last night of the meeting.

With so many ground-breaking ideas, new technologies, and innovative workshops, the AAS meeting provides a new perspective into the field of astronomy annually. Outside regular meeting sessions, collaborations occur constantly, as many of the most brilliant minds on the planet converge at one location. The meeting experience, although perhaps first intimidating for undergraduates, provides valuable insight into the inner-workings of the field.



Learn more about the IYA2009 at: <http://www.astronomy2009.org/>

A Universe of Wonder: International Year of Astronomy 2009

Music Inspired by Astronomy

A Selected Listing for the International Year of Astronomy

By Andrew Fraknoi

Part of the aim of the International Year of Astronomy is to show the connections between astronomy and other areas of human culture. Such connections are easily found in music, where astronomical ideas have found a wide range of expression. This is not a comprehensive listing, but a sampling of some of the pieces that are available on CD, and that may be of particular interest to educators and astronomy enthusiasts.

To qualify, a piece (or the composer's vision for it) has to include some real science and not just an astronomical term in the title or in a few lyrics. A more comprehensive discussion can be found in my article in *Astronomy Education Review*: <http://aer.noao.edu/cgi-bin/article.pl?id=193>

Editor's Note: We've included selections from the popular music category here. For the complete resource, including classical, Broadway, and additional categories, see: www.astronomy2009.org/static/resources/iya2009_music_astronomy.pdf.

Popular Music Available on CD

Black, Frank "Places Named After Numbers" on *Frank Black* (Electra WEA 61467). This is a love song to a black hole, with lyrics such as "And though it seems from here, That she was never there, Light beams disappear, Into her blackened hair."

Byrds "CTA 102" on *Younger than Yesterday* (Sony 64848). Back in the 1960s, there was a brief flurry of public attention to quasar CTA 102, whose radio signals were claimed to include coded information from an advanced civilization. There was nothing there, but the Byrds wrote a song about it. Radio astronomer Eugene Epstein then included the names of the Byrds in a reference in a paper on CTA 102 in the *Astrophysical Journal* (vol. 151, p. L31, second paragraph), referring to the song as "private communication."

Clannad "Sirius" on *Sirius* (RC 6846). Enigmatic lyrics appear to be about fleeing the Earth as the sun becomes a red giant and trying to reach Sirius.

Cowboy Junkies "Crescent Moon" on *Pale Sun Crescent Moon* (RCA 66344). A bluesy rock song which uses images with the phases of the moon.

Epidemic "Factor Red" on *Decameron* (Metal Blade CD). Song about a red giant star, which begins: "Retinas burn, as my eyes raise towards the dying star, Half devoured sky bleeds red, the death of a star has begun..."

Gamma Ray "Beyond the Black Hole" on *Somewhere Out in Space* (Noise 283). Interesting lyrics about a survivor of a civilization whose star has died, diving into a black hole.



The Aug. 1, 2008, solar eclipse at the point of totality. Eclipse references are common in nearly all genres of music.

Image Credit: The Exploratorium/NASA

Grateful Dead "Dark Star" on *What a Long Strange Trip It's Been* (Warner Brothers 3091) [and other CDs]. The song begins "Dark star crashes, pouring its light, into ashes," and has a memorable line about going through "the transitive nightfall of diamonds." Its sometimes surrealistic words definitely conjure up a number of images of stardust.

Hawkwind "Quarks, Strangeness, and Charm" on *Quarks, Strangeness, and Charm* (Griffin 132). Humorous song using lots of science ideas (relativity, antimatter, quarks, etc.). Makes the mistake of saying Copernicus used a telescope, but the rest is fun.

Iron Maiden "When Two Worlds Collide" on *Virtual IX* (Sony). Heavy metal song about cosmic impacts; lyrics include mentions of telescopes, declination, orbit calculations.

Knopfler, Mark "Sailing to Philadelphia" on *Sailing to Philadelphia* (Warner Brothers 47753). A song about Mason and Dixon and their surveying expedition; refers to the fact that Mason was an astronomer.

Lear, Amanda "Black Holes" on *Never Trust a Pretty Face* (1979; song also available on some imported greatest hits CDs). Compares an all-consuming love to a black hole; lyrics include "Like a black hole in the sky, You crush me from your universe, What you want you just erase without a trace, Like a fantastic goodbye."

Melua, Katie "Nine Billion Bicycles" on *Piece by Piece* (2005 CD released in England, single available by import). As part of a series of large numbers used to describe her love, she mentions the size of the universe. Physicist and author Simon Singh then took her publicly to task about using 12 billion vs. 13 billion lightyears as the radius of the observable universe. She eventually did a TV retaping with improved numbers.

Moody Blues "Higher and Higher" on *To Our Children's Children* (Polygram CD 844770). This 1969 song celebrates the Apollo 11 mission to the Moon and uses the image of tranquility (the mission landed in Mare Tranquillitatis).

O'Connell, Robbie "Galileo" on *Humorous Song* (Celtic Media CMCD 2000). An apology from the Church to Galileo.

Petty, Tom & the Heartbreakers "In the Dark of the Sun" on *Into the Great Wide Open* (MCA 1037). This song, presumably about an eclipse, includes mentions of constellations and Orion's sword. The album notes have constellation diagrams with them and the CD itself shows circumpolar constellations with the center of the turning CD being the North Celestial Pole.

Pink Floyd "Shine on You Crazy Diamond" on *Wish You Were Here* (Capitol 29750). Compares the self-destructive fading away of Syd Barret, the former leader of Pink Floyd, with the fading away of a low-mass star like the sun into a white dwarf.

Queen "'39" on *Night at the Opera* (Hollywood 61065). Song about an interstellar expedition traveling at relativistic speeds and the loneliness the crew feels because they know that everyone they knew on Earth will be dead when they return. Brian May, a member of this group, trained as an astronomer in England.

Police "Walking on the Moon" (found on several of their greatest hits compilations). Compares the feeling of walking in the low gravity of the moon ("giant steps") to being in love.

Rush "Countdown" on *Signals* (Mercury/Universal 534633). Nice description of what it is like to witness a rocket launch at Cape Kennedy.

Rush "Cygnus X-1" on *Farewell to Kings* (Mercury/Universal 534628). An interesting attempt to portray the ideas around the discovery of the first stellar-mass black hole in poetic and musical terms. Lyrics include: "Headlong into mystery, The x-ray is her siren song, My ship cannot resist her long, Nearer to my deadly goal, Until the Black Hole -- Gains Control..."

Rush "Natural Science" on *Permanent Waves* (Mercury/Universal 534630). Images from astronomy and the evolution of life are entwined with injunctions about morality.

They Might Be Giants "The Sun is a Mass of Incandescent Gas" on *Why Does a Star Shine?* (Elektra 66272-2). A re-recording of a 1959 educational song from an album called "Space Songs" (lyrics by Hy Zaret, who also wrote "Unchained Melody").

Continued on page 19

SPS Opportunities

Fall 2009



SPS student Joshua Burrow, Morehouse College, presents a poster on his research at the 2009 Zone 6 Meeting, the first zone meeting ever held in Puerto Rico.
Photo by Lydia Quijada, AIP



2009 SPS intern Leslie Watkins explores the physics of rolling objects with 3rd-grade students.

Photo by Kendra Rand, AIP

“Joy and amazement of the beauty and grandeur of this world of which man can just form a faint notion ...”.

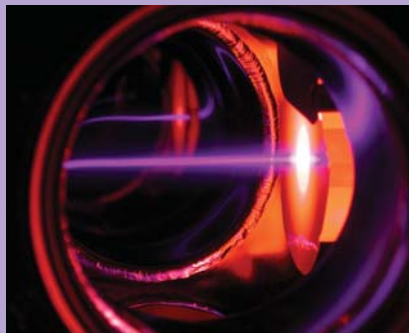
-Albert Einstein

Funding Opportunities for Physics Outreach

LaserFest on the Road: A \$10,000 Opportunity!

DEADLINE: SEPTEMBER 30, 2009

Watching your favorite movie on DVD. Surfing the web. Scanning barcodes at the grocery store. For the past 50 years, lasers have revolutionized the way we live. The 2010 milestone marks 50 years of one of the greatest inventions of the 20th century! Through a series of events and programs, LaserFest will help to showcase the prominence of the laser in today's world.



A purple laser beam slows erbium atoms emerging from an oven at 1300 C, in preparation for trapping and cooling. This process could lead to novel technologies.

Photo courtesy of NIST

The American Physical Society (APS) and the Optical Society of America (OSA) will be awarding several grants of up to \$10,000 to encourage outreach activities during 2010's LaserFest.

Proposals that cover any form of public outreach will be considered but activities should be focused on the LaserFest celebration and therefore must have a significant laser component. Special consideration will be given to proposals that impact women and minorities, and to proposals that are exceptionally innovative. Programs may be aimed at any age group. For those that are aimed at students, the thrust of the proposal must involve outreach, as distinct from education.

The main contact person for the grant must be an APS or OSA member. Not a member of APS or OSA? Your SPS Advisor probably is, or consider joining APS yourself—they offer a free one-year trial membership for students (www.aps.org/membership/student.cfm). The extent to which the grant activity involves other APS and OSA members will also be a factor in the funding decision.

Innovative and experimental approaches are encouraged, particularly if they have the potential to lead to sustained activities beyond the duration of the grant. For information on how to apply, visit www.laserfest.org/news/rfp.cfm.

The grant period will be calendar year 2010 and the total amount of the grant will not exceed \$10,000. Learn more at www.laserfest.org.



The Marsh W. White Award

DEADLINE: NOVEMBER 15, 2009

Marsh W. White Awards are made to SPS chapters "to support projects designed to promote interest in physics among students and the general public." Awards of up to \$300 are made annually on the basis of proposals submitted by active SPS chapters. In 2009, 14 chapters received Marsh White Awards (see two examples below). For application information and descriptions of past Marsh White Award winning projects, visit: www.spsnational.org/programs/awards/white.htm.

Marsh White Awards in Action

Rhodes College: As part of the International Year of Astronomy (IYA2009), the Rhodes College SPS chapter used its 2009 Marsh White Award to join forces with other local organizations and host the NASA-sponsored "From Earth to the Universe" exhibit in the foyer of the Memphis Central Library.



Library patrons explore the universe through the Rhodes College "From Earth to the Universe" exhibit.

Photo by Bill Wilson, Memphis Astronomical Society (Graduate of Rhodes College)

Penn State University: Penn State's SPS chapter hosted its second annual set of physics-themed stations at the College of Science and Pennsylvania Space Grant-sponsored Exploration Day on April 18, 2009. With a theme of a "superhero training academy," students, mainly in grades 1-8, went through a series of eight physics-themed stations in an attempt to learn how to utilize their superhero powers.

Students learned how to generate electrical energy (bikes connected to light bulbs), freeze their enemies (liquid nitrogen), speed through the air (kid-sized hovercraft), and more, mimicking the powers of well-known superheroes associated with the stations. Those who completed all eight stations were given a certificate of completion, as well as a prize for their efforts. The event drew approximately 2,500 people.

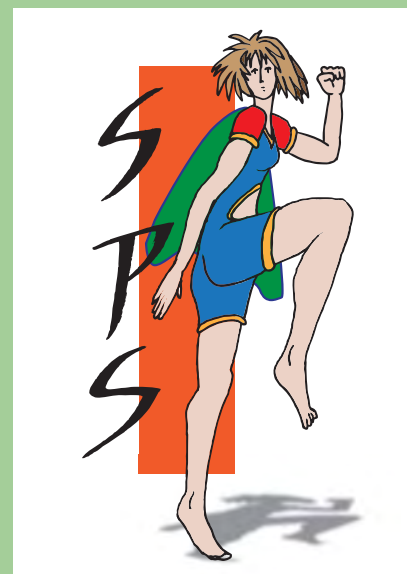


Illustration by Phillip Payette

\$2,000 for Chapter Research Project The Sigma Pi Sigma Undergraduate Research Award

Any Society of Physics Students chapter can apply for this award whether or not the campus has a chapter of the physics honor society, Sigma Pi Sigma. The award is named the Sigma Pi Sigma Undergraduate Research Award because it is made possible by donations provided by members of the honor society.

REQUIREMENTS

1. Only ONE proposal may be submitted by each SPS chapter.
2. It must contain a precise statement of the proposed CHAPTER research activity to be completed within a calendar year.
3. It must contain a budget requesting not more than \$2,000 from SPS.
4. It must be signed by the advisor and appropriate officers of the chapter.

DEADLINE

All proposals must be postmarked or emailed on or before **NOVEMBER 15**. For more information about submitting a proposal and evaluation criteria, see: www.spsnational.org/programs/undergrad.htm.

Check out some of the winners of 2008-09!



Augsburg College

Development of "Ground Truth" Data Sets for Live Cell Imaging Using Physarum Polycephalum

The College of New Jersey

Using Fluorescent Dust to Obtain a Three Dimensional Analysis of a Dusty Plasma Part II

University of Dallas

Extrasolar Planetary Search Using the Transit Method and the Gunnison Valley 30-Inch Telescope

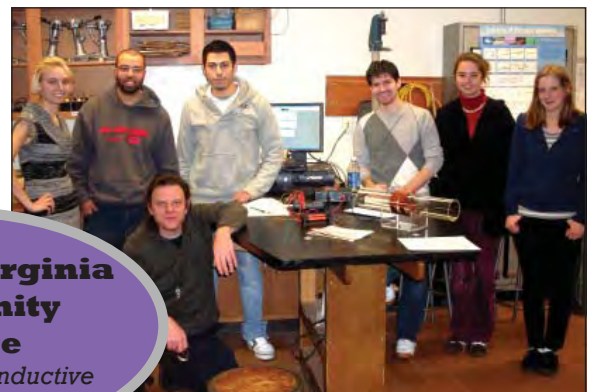
Rowan University

Reconfiguration of a Four-Cathode Sputter Deposition Chamber



Chicago State University

The Detection of Cosmic Rays



Northern Virginia Community College

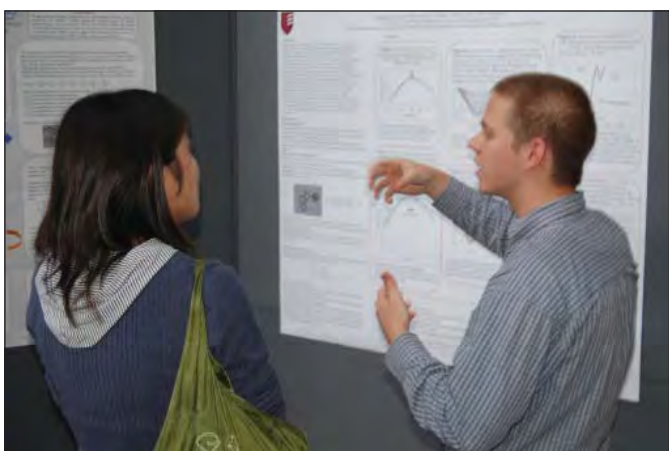
Experiments in Inductive Magnetic Levitation

Undergraduate Research

“We advocate that every student majoring in physics and/or astronomy engage in a meaningful undergraduate research experience.”

Thus spake the governing council of the Society of Physics Students (SPS) and of Sigma Pi Sigma, the physics honor society, adopting the above statement on undergraduate research for general dissemination, with the final approval process being completed on December 1, 2008.

SPS has a long history of advocating undergraduate research through such efforts as the publication of *“How to Involve Students in Research: A Field Guide for Faculty”* (1995), the maintenance of the Sigma Pi Sigma Undergraduate Research Awards, the Summer Research Clearinghouse on *The Nucleus* (www.compadre.org/student/), the support of student research presentations at professional society meetings, and through the development of JURP, the *Journal of the Undergraduate Research in Physics* (www.jurp.org). See the Call for Papers below.



Why adopt a “Statement on Undergraduate Research,” anyway?

The statement above was proposed as an official policy statement of SPS with the idea that it would be useful as an announcement to physics departments, as a tool to be used by others in defending undergraduate research, and as a possible statement for other societies to consider adopting.

For a detailed rationale of such statements, along with many supporting references on undergraduate research, see the “Call to Action”:

www.spsnational.org/governance/statements/education_reform.pdf .

JURP

The Online

Journal of Undergraduate Research in Physics

Published by the Society of Physics Students & Sigma Pi Sigma

Call for Papers

Journal of Undergraduate Research in Physics — www.jurp.org

JURP is a peer-reviewed journal of the Society of Physics Students (SPS) for archiving research conducted by undergraduate physicists. Papers in experimental physics, theoretical physics, physics history, or educational research in physics are welcome. Whether you performed cutting-edge research that led to new discoveries, cultivated insights that deepen our appreciation of well-established physics, or asked serious questions about physics education or history, you have something original to contribute to the ongoing conversation about physics.

The research must have been performed while the student authors were undergraduates, although the paper may be submitted soon after graduation. The primary authors of papers submitted to JURP should be the undergraduates who conducted the work, but faculty mentors may be listed as co-authors if that would be appropriate. There are no submission deadlines, as JURP is published online: www.jurp.org .

Send a PDF of your manuscript to Dwight E. Neuenschwander, Editor, at dneuensc@snu.edu .

The History of Cosmology as I Have Lived Through It

By Victor S. Alpher, PhD

Editor's comment: Ralph A. Alpher (1921-2007) was a founder of Big Bang cosmology. His 1948 dissertation on primordial element abundances by neutron capture laid the foundation for modern big bang nucleosynthesis calculations, and led that same year to the prediction by Alpher and Robert Herman of the existence and present temperature of the cosmic microwave background radiation. The CMBR forms the crucial signature of a universe that began with a "Big Bang," and its power spectrum has opened the era of "precision cosmology." We have been privileged to publish a three-part biography of Ralph Alpher, written by his son, Dr. Victor Alpher. Because of its significance, we wanted to publish Part 3, 'The History of Cosmology as I Have Lived Through It,' in its entirety in one issue of the Observer. However, because of its length, we are obliged to publish it online. Part 3, complete and with photos, may be found at www.spsobserver.org. The three-part series has also been published in the Spring 2008, Fall 2008, and Spring 2009 issues of Radiations. We trust you will enjoy this article as Victor Alpher offers us a glimpse into the life and work of Ralph A. Alpher. Here is an excerpt:

*"Besides his great intellectual achievements, Ralph Alpher was a gentleman of unflinching kindness and a keen sense of justice."
-Samuel L. Marateck[1]*

A Personal End and a Beginning

In 1948 my father earned a doctorate at George Washington University for his dissertation on nucleosynthesis. The dissertation argued that the elements were built by neutron capture processes, with beta decays, in the hot environment of the early big-bang universe. This calculation was placed before the physics community in the now-famous " $\alpha\beta\gamma$ " paper of 1948, "The Origin of Chemical Elements."^[4] Gamow's "prank" added Hans Bethe's name to obtain the $\alpha\beta\gamma$ association.^[5] The 2005 National Medal of Science, presented to Ralph A. Alpher in 2007, was conferred "For his unprecedented work in the areas of nucleosynthesis, for the prediction that universe expansion leaves behind background radiation, and for providing the model for the Big Bang theory" (see Figure 1). The paper of 1948 and the 2007 National Medal of Science form the bookends to his life as a cosmologist.

By the time I was 10 years old, I was aware that my dad was a special man and unique scientist. More than once, at interviews for academic positions I was greeted with the question "Are you Ralph Alpher's son?" For example, as a graduate student at Vanderbilt University, my committee chair, Professor Richard Blanton, announced (without my knowledge) my intellectual pedigree to the faculty before whom I would have to defend my graduate work. I have developed great empathy for the offspring of famous people! My father's reputation influenced my life in many unexpected ways.

In October 2006, John C. Mather and George Smoot were awarded the third and fourth Nobel Prizes for precision observations of the cosmic microwave background radiation (CMBR), observations that greatly strengthened support for the big bang model. They headed



Ralph A. Alpher (1921-2007) was a founder of Big Bang cosmology.

Photo courtesy of Victor S. Alpher

large teams that designed and managed the cosmic background explorer (COBE) satellite, launched in 1989. My father and Bob Herman were invited to attend the COBE launch, which they did.^[6]

Since my dad's passing in 2007, several of his colleagues have graciously spoken with me about their memories of my dad and their work with him through the decades since the 1940s. Many of these people have been important role models in my life. They showed me how meaningful a life in science can be. This paper also acknowledges them.

My father spoke and wrote often about his experiences, but some events he never disclosed in detail. When he left his papers to me, he knew I would study and interpret them. His "unfinished business" became mine.

Ralph A. Alpher's Career in Cosmology Begins

Dad wrote *two* dissertations as a graduate student of George Gamow's at George Washington University. The first one examined density perturbations that would lead to galaxy formation in an expanding universe. In 1946, when he had just about completed it, Gamow came into Dad's office at Johns Hopkins University Applied Physics Laboratory (JHUAPL) where both of them were consultants. Gamow was "waving in his hand" a copy of the *Journal of Physics of the USSR* in which Evgenii Lifshitz reported the same findings that my dad reached in his dissertation. So Ralph had to begin anew on another dissertation topic, for as he told me many years later, he had been "scooped...."

Continued online at www.spsobserver.org

History of Big Bang Cosmology, Part 6: Nucleosynthesis After Alpher

Dwight E. Neuenschwander

I. Post-Alpher Nucleosynthesis Developments

In this series we are examining some high points in the history of big bang cosmology. Part 1 recalled how astronomers measured the universe to be vastly larger than the Milky Way.[1] Parts 2 and 3 described how Albert Einstein started modern cosmology with his model of a closed static universe and contrasted it with the alternative solution found by Willem de Sitter.[2,3] Part 4 described the 1922-23 dynamic models of Alexander Friedmann, whose equations predicted the possibility of an expanding universe.[4] Those results were re-discovered by Georges Lemaître in 1927. Part 5 told how Ralph A. Alpher's dissertation of 1948 (George Gamow was his PhD advisor) was the first attempt to predict the early-universe abundances of the elements due to out-of-equilibrium neutron capture processes.[5]

This concept envisioned nuclei of various mass numbers A built up by neutron capture; afterward beta decays convert some of the neutrons to protons. Along the way Alpher introduced the term *ylem*, (pronounced $\tilde{r}\text{-}l\text{-}\tilde{e}m$) for "the primordial substance from which the elements were formed." The essential points of the dissertation were first summarized in the famous " $\alpha\beta\gamma$ " paper of April 1948, bearing the title "The Origin of Chemical Elements." [6] Upon integrating the coupled rate equations (most done numerically), element-building by neutron capture was estimated to be essentially finished at $t \approx 5$ min. Later that same year Alpher developed these calculations more fully in a longer paper. Further refinements formed the subject of another 1948 paper by Alpher and Robert Herman that included the effects on the nuclear abundances of the expansion and beta decay. Many papers on the early universe by these authors were forthcoming over the next several years.[7] Here in Part 6 of our series we relate how nucleosynthesis calculations were carried forward by others who built on the foundation laid down by Alpher, Gamow, and Herman in 1948. The cosmic background radiation was predicted by Alpher and Herman that same year; [8] more will be said of it in an upcoming article.

In 1951 Enrico Fermi and X. Turkevitch showed that elements beyond helium could not be made in quantity within the ylem, because the nuclei with $A = 5$ and $A = 8$ are notoriously unstable. Their instability comes from the stability of helium-4 with its "closed shells" of protons and neutrons. A nucleus with $A = 8$ is a pair of helium-4 nuclei and easily splits in two. Adding one more baryon to He-4 to make $A = 5$ puts the nucleus in an unstable situation analogous to the loosely bound valence electron in the sodium atom. These gaps at $A = 5$ and

8 can be jumped to produce in trace amounts the elements beyond them through improbable sequences of reactions, such as three He-4 nuclei colliding within 10^{-15} s to produce a nucleus of carbon-6 (the "triple-alpha" process). But few such event sequences will occur in Alpher's five minutes. It remained for later investigators, notably Bainbridge, Fowler, et al., to show in 1957 how the heavy elements could be synthesized routinely in stellar fusion and supernovas,[9] but the first stars did not begin to shine until a billion years or so after the big bang, outside the story of nucleosynthesis in the ylem.

Through the 1960s and continuing into the present, primordial nucleosynthesis calculations have become an industry. The papers that carried the ball through these decades include those authored by P.J.E. Peebles,[10] R.A. Wagoner, W.A. Fowler and F. Hoyle,[11] R.V. Wagoner,[12] D.N. Schramm,[13] D.N. Schramm and R.V. Wagoner,[14] A.M. Boesgaard and G. Steigman,[15] K.A. Olive, D.N. Schramm, G. Steigman, and T.P. Walker,[16] Walker, Steigman, Schramm, Olive, and H. Kang,[17] and others. The problem these experts have solved is wonderfully complicated. Demonstrating *why* those calculations are complicated—without having to actually *do* them in all their complexity—sets my goal for this article! These calculations feature dozens of coupled differential equations that must be solved simultaneously. Their reaction rate coefficients depend on isotope densities and reaction cross sections, which in turn depend on the temperature and thus the time. Clearly in realistic models one must resort to numerical integration of the rate equations. Then these calculations of the *primordial* abundances have to be corrected for subsequent nucleosynthesis in stars, so measurements can be compared to theory. These are not problems to be solved over a weekend!

But if we confine our attention to the synthesis of primordial hydrogen-1 and helium-4 only, then the problem becomes tractable. Here I present an oversimplified model that exchanges completeness for accessibility. It does not include all the relevant effects, but aims to give a glimpse of how the game is played. Such a simplified calculation may nurture deeper appreciation for the challenges faced by those who skillfully carry out the more realistic programs. The real experts attempt the vastly more ambitious task of calculating the primordial abundances of all three isotopes of hydrogen, both isotopes of helium, as well as lithium, beryllium, carbon, and other light elements—where the answers can be on the order of parts-per-trillion!

The early universe is modeled with

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gravitational physics, thermodynamics, and particle/nuclear physics. The gravitation sector relies on general relativity with the Friedmann-Lemaître-Robertson-Walker (FLRW) metric, which features a cosmic scale factor $a(t)$ that describes the rescaling of space as time t elapses. The FLRW metric also contains a curvature parameter $k = +1$ (-1) for the closed (open) universe, with $k = 0$ for no-curvature geometry. The equations of gravitation allow the possibility of the "cosmological constant" $\Lambda \geq 0$. From Part 4, let us recall one of the equations that controls the evolution of $a(t)$:

$$(da/dt)^2 = \kappa \rho a^2 + \frac{1}{3} \Lambda a^2 - k \quad (1)$$

where ρ denotes the energy density and $\kappa \equiv 8\pi G/3c^2$, with $G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2 =$ Newton's constant of universal gravitation and $c = 3 \times 10^8 \text{ m/s} =$ speed of light in vacuum. In the very early universe, which concerns us here, the density is large, so Λ and k may be neglected.

The expansion of the universe proceeds according to Hubble's Law, where the relative velocity of a pair of points is proportional to their separation, with Hubble's parameter $H = (1/a)da/dt$ the proportionality factor. By Eq. (1), in the early universe

$$H = (\kappa \rho)^{1/2}. \quad (2)$$

In part 4 we also saw that the equations of general relativity and thermodynamics together say that the expansion proceeds adiabatically, cooling as $a \sim 1/T$, and that T evolves in time according to

$$T^2 t \approx 2 \times 10^{20} \text{ K}^2 \text{ s}. \quad (3)$$

The particle/nuclear physics provides input for the denizens of the ylem and their interactions that lead to structures as the universe expands and cools. So long as $k_B T \gg mc^2$ (where $k_B =$ Boltzmann's constant $= 8.617 \times 10^{-5} \text{ eV/K}$), particle-antiparticle pairs are as readily created from photons (γ) as they are annihilated into photons,

$$\gamma + \gamma \leftrightarrow m + \bar{m} \quad (4)$$

where m and \bar{m} denote a particle of mass m and its antiparticle, respectively. But when $k_B T < mc^2$, the annihilations still proceed but pair productions are quenched. Setting $k_B T = mc^2$ determines the temperature threshold above which particles and their antiparticles exist in dynamic equilibrium with photons. Some threshold temperatures and corresponding times are given in Table 1.

If some symmetry-breaking reactions occurred whereby antiparticles could

Spring/Summer 2009

TABLE 1

PARTICLE	MASS (MeV/c ²)	$T = mc^2/k_B$ (K)	t (s)
neutron	~1000 (939.550)	1×10^{13}	2×10^{-6}
proton	~1000 (938.256)	1×10^{13}	2×10^{-6}
electron & positron	0.511	6×10^9	5.7
neutrinos	0 or near 0	~ 0	~ ∞
photon	0	0	∞

spontaneously decay to other species at rates faster than their corresponding particles (such reactions are known to exist),[18] then after the unreplenished annihilations were completed, some particles would be left as survivors—a mechanism for explaining the abundance of matter over antimatter in the universe.

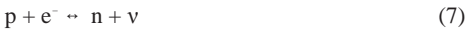
II. A Simplified Model of Primordial Helium Synthesis

Let us take up the story at $t = 0.01$ s, when $T \approx 1.4 \times 10^{11}$ K and $k_B T \approx 12$ MeV. The ylem may be considered an ideal gas of photons, free electrons and neutrinos and their antiparticles, and free neutrons and protons. The leptons are relativistic because for them $k_B T \gg mc^2$, but the baryons are nonrelativistic because for them $k_B T \ll mc^2$. The energy and momentum of a free particle of mass m are related by

$$E^2 = (pc)^2 + (mc^2)^2 \quad \text{all speeds, } 0 \leq v \leq c \quad (5)$$

$$E = p^2/2m + mc^2 \quad \text{nonrelativistic } (v \ll c). \quad (6)$$

The neutrons and protons transform back and forth into one another by collisions with the leptons:



Besides these collision-induced reactions, a free neutron may also spontaneously decay into a proton,



with a half-life of about 887 s.[19]

Let N be the number of all baryons, and N_i the number of baryons of species i ($i = p$ or n). Therefore $N = N_n + N_p$, and in terms of $X_i = N_i/N$,

$$1 = X_n + X_p. \quad (10)$$

From statistical mechanics we know that in thermal equilibrium, a particle will be found in a state of energy E with probability proportional to the Boltzmann factor $\exp(-E/k_B T)$. The relative abundance X_i measures this probability. The small n - p mass difference (1.3 MeV/ c^2) leads to

$$X_n/X_p = \exp(-1.3 \text{ MeV}/k_B T). \quad (11)$$

This together with Eq. (10) gives

$$X_n = [1 + \exp(+1.3 \text{ MeV}/k_B T)]^{-1}. \quad (12)$$

Our goal is to determine the mass fraction Y of baryonic matter that ends up as helium-4 nuclei, with the remainder left as hydrogen-1 nuclei (we are ignoring all other isotopes).[20] With m denoting the generic nucleon mass, we may write

$$Y = \frac{\text{(mass of all helium-4 nuclei)}}{\text{(mass of all baryons)}} \\ \approx 4m (X_{\text{He-4}}) / (m X_n + m X_p). \quad (13)$$

But the number of helium-4 nuclei is half the number of neutrons, and thus

$$Y = 2 X_n. \quad (14)$$

We therefore need X_n at the time of nucleosynthesis, the first moment when nuclear fusion can survive photofission in the ylem. Along the way, the reactions of Eqs. (7) and (8) are quenched when, as the universe expands and the gas thins and cools, the collision rate drops to less than the universe's expansion rate. After that only neutron decay continues decreasing X_n and increasing X_p . We will work our way in steps to the moment of nucleosynthesis.

The rate equations for the reactions of Eqs. (7) and (8) are

$$dX_n/dt = -k_1 X_n + k_2 X_p \quad (15)$$

$$dX_p/dt = -k_2 X_p + k_1 X_n. \quad (16)$$

The rate equation for neutron decay of Eq. (9), that holds after the collision-induced reactions cease, says

$$dX_n/dt = -h_1 X_n \quad (17)$$

where $h_1 = (\ln 2)/887\text{s} = 7.8 \times 10^{-4} \text{ s}^{-1}$ for the radioactive decay of the free neutron.

For collisions with electrons that turn protons into neutrons (for example) at the rate $k_2 X_p$, we need proton targets and a current of electrons coming at them. X_p measures the proton abundance; k_2 the rate at which they are hit by electrons. The relevant electron current is the product of its current density and the target area offered by a proton. The current density is the product of the electron number density n_e and the electron velocity ($\approx c$ because the electrons are relativistic). The target area, centered on the proton within which an electron must strike, is called the "cross section" σ . Therefore

$$k_2 = n_e c \sigma. \quad (18)$$

So now we must evaluate n_e and σ . Let's turn to the number density first.

First, we recall some comments about statistical mechanics in general. The average number of identical particles $dN(\mathbf{p}, \mathbf{r})$ that lie within the momentum range \mathbf{p} to $\mathbf{p} + d\mathbf{p}$ and between locations \mathbf{r} and $\mathbf{r} + d\mathbf{r}$ is given by

$$dN(\mathbf{p}, \mathbf{r}) = g f(\mathbf{p}, \mathbf{r}) d^3p d^3x/h^3 \quad (19)$$

where g denotes the multiplicity for the spin degrees of freedom, $h = 4.136 \times 10^{-15} \text{ eV s}$ denotes Planck's constant, and f denotes a distribution function:

$$f = \{\exp[(E - \mu)/k_B T] \pm 1\}^{-1} \quad (20)$$

where the plus sign holds for Fermi-Dirac particles with odd-half-integer spin, and the minus sign holds for Bose-Einstein particles that carry integer spin. The quantity μ denotes the chemical potential, the energy required to remove one particle from the system. The total number of identical particles follows by integrating over all possible momentum and position values:

$$N = 4\pi g V/h^3 \int_0^\infty \{\exp[(E - \mu)/k_B T] \pm 1\}^{-1} p^2 dp, \quad (21)$$

where V = total volume available to the particles, and we have written the momentum in spherical coordinates.

Now we can return to the task of finding the number density of those electrons that are going to collide with protons to make neutrons. For highly relativistic particles the masses and chemical potentials are negligible. Therefore $E \approx pc$, so that

$$N_e \approx 4\pi g V/h^3 \int_0^\infty \{\exp(pc/k_B T) + 1\}^{-1} p^2 dp. \quad (22)$$

With the change of variable $x \equiv pc/k_B T$ this gives

$$N_e = 4\pi g (k_B T/hc)^3 I \quad (23)$$

$$\text{where } I = \int_0^\infty (1 + e^x)^{-1} x^2 dx. \quad (24)$$

To find an order-of-magnitude estimate we can quickly approximate I by neglecting the 1 in its denominator, in which case $I \approx 2$. In that case, with $g = 2$ and denoting particle number densities $N/V \equiv n$, from Eq. (23) we have $n_e \approx 16\pi (k_B T/hc)^3$.

However, the integral I offers a pedagogical

example of integration techniques that are among the tools of the trade. Introduce $z = e^{-x}$ and write the exponential piece of the integrand as $z/(1+z) = z/[1 - (-z)]$, then use the geometric series

$$1/(1-y) = 1 + y + y^2 + y^3 + \dots \quad (25)$$

This allows us to evaluate the integral term by term. Using the definite integral

$$\int_0^{\infty} x^n e^{-Ax} dx = n! / A^{n+1} \quad \text{for } A > 0 \quad (26)$$

these steps give

$$I = 2[1 - (1/2)^3 + (1/3)^3 - (1/4)^3 + \dots] \quad (27)$$

Emerging in this alternating series we will see an example of the ‘‘Riemann zeta function,’’

$$\zeta(x) \equiv 1 + 1/2^x + 1/3^x + \dots \quad (28)$$

as follows: After separating the positive and negative series and factoring $1/6$ out of the latter, we find $I = (3/2)\zeta(3)$. From the math tables,[21] $\zeta(3) \approx 1.202$, so $I \approx 1.803$, near our estimate. Therefore we have

$$n_e = [2\zeta(3)/\pi^2](k_B T/\hbar c)^3 \quad (29)$$

where $\hbar = h/2\pi = 6.582 \times 10^{-16}$ eV s denotes the reduced Planck constant.

Next we turn to the cross section. From weak interaction physics and dimensional analysis, $\sigma \sim (\hbar c G_F E)^2$ (modulo dimensionless constants), where $G_F = 1.17 \times 10^{-5}$ GeV⁻² denotes the ‘‘Fermi constant’’ that Enrico Fermi introduced in the 1930s for his model of the weak interaction.[22] E denotes the energy of the lepton. Approximating the latter with $k_B T$, we take $\sigma \approx (\hbar c G_F)^2 (k_B T)^2$. So at last, for k_2 we obtain

$$k_2 \approx (2/\hbar \pi^2) G_F^2 (k_B T)^5 \approx 5 \times 10^{-32} (k_B T)^5 / \text{eV}^5 \text{ s}. \quad (30)$$

The collision-induced reactions of Eqs. (7) and (8) will cease the moment their collision rates and the expansion rate become equal, for example, when $k_2 = H$. Turning to Eq. (2) for H , in the relativistic gas of the early universe most particles are ‘‘photon-like,’’ their masses still negligible compared to their kinetic energies. Therefore we use an extension of Stefan’s law for the energy density,

$$\rho = (g_{\text{all}}/2) \sigma_o T^4 \quad (31)$$

where $\sigma_o = \pi^2 k_B^4 / (15 \hbar^3 c^3)$ and g_{all} denotes the sum of the spin polarization multiplicities of all particle species included ($g_{\text{all}} \sim 10$ for electrons, neutrinos and their antiparticles, and the photons).[23] These considerations give

$$H = [40\pi G \sigma_o / 3c^2]^{1/2} T^2 = 4.8 \times 10^{-21} T^2 / \text{K}^2 \text{ s}. \quad (32)$$

Equating the expansion and collision rates, $k_2 = H$, we obtain (after doing some rounding) [24] $T \approx 1 \times 10^{10}$ K, so that $k_B T \approx 0.86$ MeV when the collision-induced weak interactions of

Eqs. (7) and (8) cease. By Eq. (4) this occurs at $t \approx 2$ s, and according to Eq. (12) the neutron abundance then is about $X_n \approx 0.18$.

From 2 s onward until the time that newly fused nuclei can survive the assault of photons, the radioactive decay of neutrons decreases X_n and increases X_p . Therefore Eq. (17) gives

$$X_n = 0.18 \exp[-h_i(t - 2 \text{ s})]. \quad (33)$$

The radioactive decays of neutrons will cease when they become bound with protons into nuclei. Let us estimate the time at which fusion products become stable against photofission in the ylem.

The fusion of helium proceeds through the intermediate state of the deuteron, a bound state of one proton and one neutron that is held together with a fragile binding energy of 2.2 MeV. For fusion to occur irreversibly we require that the number density of photons with energy greater than 2.2 MeV drop to less than the number density of deuterons. For the onset of fusion we require

$$n_{\gamma(E > 2.2 \text{ MeV})} = n_D. \quad (34)$$

To obtain the number density of photons of above 2.2 MeV requires us to sum over all momenta from 2.2 MeV/c $\equiv p_o$ and higher:

$$n_{\gamma(E > 2.2 \text{ MeV})} = 4\pi g/h^3 \int_{p_o}^{\infty} [\exp(pc/k_B T) - 1]^{-1} p^2 dp. \quad (35)$$

With the change of variable $x = pc/k_B T$, and with $g = 2$ for the photon polarization states, this becomes

$$n_{\gamma(E > 2.2 \text{ MeV})} = (1/\pi^2)(k_B T/c)^3 J(x_o) \quad (36)$$

$$\text{where } J(x_o) \equiv \int_{x_o}^{\infty} [e^x - 1]^{-1} x^2 dx. \quad (37)$$

Using again the geometric series and integrating term by term, we derive

$$J(x_o) = \sum_{j=1}^{\infty} [(x_o^2/j) + (2x_o/j^2) + (2/j^3)] \exp(-jx_o). \quad (38)$$

Because $x_o = 2.2 \text{ MeV}/k_B T$, and $k_B T < 0.86$ MeV when fusion commences, we expect $\exp(-x_o) \ll 1$ [note that $\exp(-2.2/0.86) = 0.0775$] and therefore the infinite series should be dominated by the $j = 1$ term. Hence we put

$$J(x_o) \approx [x_o^2 + 2x_o + 2] \exp(-x_o). \quad (39)$$

The number density of the deuteron takes a bit more work. The free baryons and any nuclei have non-relativistic kinetic energies, $mc^2 \gg k_B T$, when the universe has cooled sufficiently for fusion to occur. For both bosons and fermions, for a nuclear species of mass number A and charge Z that finds itself in thermal equilibrium, the non-relativistic limit of Eq. (21) gives[25]

$$n_A = g_A [(m_A c^2)(k_B T) / 2\pi(\hbar c)^2]^{3/2} \times \exp[-(m_A c^2 - \mu_A)/k_B T]. \quad (40)$$

If the nuclei are also in chemical equilibrium with the protons and neutrons, then

$$\mu_A = Z \mu_p + (A - Z) \mu_n. \quad (41)$$

Writing Eq. (40) for $i = p$ or n , we may invert it to express the chemical potential of the proton or neutron in terms of the temperature:

$$\exp(-\mu_i/k_B T) = 1/2 (2\pi\hbar^2/mk_B T)^{3/2} \times n_i \exp(-m_i c^2/k_B T) \quad (42)$$

where $m \equiv 940 \text{ MeV}/c^2$ because the 1.3 MeV mass difference between the neutron and proton can be neglected in coefficients outside the exponent. When we put Eqs. (41) and (42) into Eq. (40) and practice our algebra of exponents, we cheerfully obtain

$$n_A = g_A A^{3/2} 2^{-A} (2\pi\hbar^2/mk_B T)^{3(A-1)/2} n_p^Z n_n^{A-Z} \times \exp(B_A/k_B T) \quad (43)$$

where B_A denotes the binding energy of the nucleus $A(Z)$,

$$B_A = [Zm_p + (A - Z)m_n - m_A]c^2. \quad (44)$$

For the spin-zero deuteron we set $A = 2$, $Z = 1$, and $g_D = 1$:

$$n_D = 2^{-1/2} (2\pi\hbar^2/mk_B T)^{3/2} n_p n_n \exp(B/k_B T) \quad (45)$$

where $B = 2.2 \text{ MeV}$. With n denoting the number density of free neutrons plus protons, from Eqs. (10)-(12) we may write $n_p = n - n_n$ and $n_n = nX_n = n(1 + e^{\delta/k_B T})^{-1}$ where $\delta = 1.3 \text{ MeV}$. In addition, we define the baryon-to-photon ratio $\eta \equiv N/N_\gamma = n/n_\gamma$ where n_γ denotes the number density of photons of all energies. Therefore we may replace n with $n_\gamma \eta$. For the number density of deuterons we now have

$$n_D = 2^{-1/2} (2\pi\hbar^2/mk_B T)^{3/2} n_\gamma^2 \eta^2 \exp[(\delta+B)/k_B T] \times [1 + \exp(\delta/k_B T)]^{-2}. \quad (46)$$

To find n_γ for all photons we return to Eqs. (36) and (37), replace x_o with zero, and obtain

$$n_\gamma = [2\zeta(3)/\pi^2] (k_B T/\hbar c)^3. \quad (47)$$

It will prove convenient to notice that

$$n_{\gamma(E > 2.2 \text{ MeV})} = n_\gamma [J(x_o) / 2 \zeta(3)]. \quad (48)$$

Our criterion for the onset of helium synthesis, Eq. (34), now becomes

$$J(x_o) / 2 \zeta(3) = 2^{-1/2} (2\pi\hbar^2/mk_B T)^{3/2} n_\gamma \eta^2 \times \exp[(\delta+B)/k_B T] [1 + \exp(\delta/k_B T)]^{-2} \\ = [4 \zeta(3)/\pi^{1/2}] [k_B T/mc^2]^{3/2} \eta^2 \exp[(\delta+B)/k_B T] \times [1 + \exp(\delta/k_B T)]^{-2}. \quad (49)$$

Now take the logarithm of both sides:

$$\ln [J(x_0) \pi^{3/2} / 8 \zeta^2(3)] = 3/2 \ln (k_B T / 940 \text{ MeV}) + 2 \ln \eta + 3.5 \text{ MeV} / k_B T - 2 \ln [1 + \exp(1.3 \text{ MeV} / k_B T)]. \quad (50)$$

With Eq. (50) we find the temperature at the onset of deuterium production. However, you will notice that the baryon-to-photon ratio η still sits there as an undetermined parameter. It must be fit to data. The experts choose about a billion photons to every baryon, $\eta = 10^9$. Their reason for doing so is that this value of η gives a good fit for *all* the element abundances, not only deuterium. If we accept this value, a temperature of about $T = 8 \times 10^8 \text{ K}$ gives $k_B T \approx 0.07 \text{ MeV}$. Then $x_0 = 31.4$ and $J(x_0) \approx 2.43 \times 10^{-11}$; we also recall that $\zeta(3) \approx 1.202$. With these values, the left-hand side of Eq. (50) becomes about -24.9 and the right-hand side about -25.6 . We'll accept this as close enough, and announce that deuterium fusion, and with it the fusion of helium, occurs in our simplified model at $T \approx 8 \times 10^8 \text{ K}$. According to Eq. (3), this temperature occurs at $t = 297 \text{ s}$, and Eqs. (12) and (14) give a neutron abundance of 0.13 and a relative helium-4 mass abundance of 0.26, leaving 0.74 as hydrogen-1. In other words, about 26% of the primordial baryonic mass in the universe "freezes out" as helium-4, leaving the rest as hydrogen-1, about five minutes after the big bang, as Alpher first estimated.

How do these numbers compare to reality? Olive and Steigman,[26] in a thorough analysis of observations, concluded $Y_{\text{obs}} = 0.232 \pm 0.003(\text{statistical}) \pm 0.005(\text{systematic})$. Models more realistic than ours calculate $0.235 \leq Y \leq 0.245$ and $0.236 \leq Y \leq 0.243$. [15,16] Taking $Y = 0.24$ an "observed" value, we find our simplified model to be about 8% larger. That our estimate comes out a bit too large is not surprising since we ignored all other sinks of neutrons, such as hydrogen-2, hydrogen-3, helium-3, and "metals" (post-helium elements).

III. Pointing Toward More Realistic Models

The more realistic models must worry about all the leptons (muons, taus, and their neutrinos), and of course all the other isotopes besides H_1^1 and He_2^4 . That means there will be a huge array of coupled differential equations, with temperature-dependent rate coefficients. Every channel whereby one isotope can turn into another by decay or collision must appear in the rate equations.

Whereas in our simplified model we imagined the transition of free neutrons and protons into helium-4 to be instantaneous, more realistically one tracks all isotope abundances as functions of temperature and time.

Let's return to the number density of various isotopes, Eq. (40), and add up the baryon masses, where Nm is approximately the mass of all baryonic matter (with N the number of all baryons and N the number of nuclei having mass number A , each of mass $\approx Am$). Eq. (10) generalizes to

$$1 = X_n + X_p + \sum_A X_A \quad (51)$$

where $X_A = AN_A/N = A n_A/n$. Recall $\eta = N/N_\gamma = n/n_\gamma$, replace n with ηn_γ , and re-trace the steps we went through for deuterium. One eventually obtains, in natural units,[25]

$$X_A = g_A \eta^{A-1} [\zeta(3)]^{A-1} 2^{(3A-5)/2} \pi^{(1-A)/2} A^{5/2} (T/m)^{3(1-A)/2} X_p^Z X_n^{A-Z} \exp(B_A/T). \quad (52)$$

Here we have an expression for the mass fraction of element $A(Z)$ as a function of temperature, with η as a parameter to be fit to data. A good fit can be obtained for all elements, to an accuracy of a few parts out of a thousand, if η describes a billion-to-one photon-to-baryon ratio. But this radiation cannot leave the universe; it must still be with us! Therefore the nucleosynthesis calculations within the big bang paradigm make a crucial prediction: the existence and temperature of the cosmic background radiation, to which we will turn next.

Acknowledgment

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- [22] M. Leon, *Particle Physics: An Introduction* (Academic Press, 1973), Ch. 11.
- [23] The factor of $g_{\text{all}}/2$ needs explaining: The energy density of electromagnetic radiation is $\rho_{\text{rad}} = \sigma_0 T^4$ where $\sigma_0 = \pi^2 k_B^4 / 15 h^3 c^3$, which already includes a factor of 2 for the polarization states of light. Therefore we divide the 2 out, then put back in g_{all} the spin multiplicities of all species of relativistic particles we consider in the ylem. Technically, for each fermion species there's a $1/2$ that we approximate as 1.
- [24] The experts obtain about $T \sim 10^{10} \text{ K}$ for this temperature. In the interest of full disclosure, to get it in our simplified model with the input numbers we have requires me to round k_B to $10 \times 10^{-5} \text{ eV/K}$. These give $T^3 = 10^{30} \text{ K}^3$ and thus $T = 10^{10}$, an order-of-magnitude estimate here. But drastic approximations already exist in setting up the calculation: for instance, the weak interaction cross section was "derived" by dimensional analysis only, $\sigma = (\hbar c G_F E)^2$ so that any dimensionless constants it carries are unknown. One really should use cross sections based in the electroweak interaction. Other approximations are also mentioned in the text. This calculation is as honest as it can be, while recognizing that we know what the answer is "supposed" to be, and we are attempting to get it by using only concepts encountered in a "modern physics" course. Simplicity and precision seem to be orthogonal values sometimes. That one can come so close with "modern physics" course arguments I find astonishing.
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Spotlight on SPS Outreach

Pi Day, SPS Style

By Thomas Olsen and Kendra Rand, SPS Staff

March 14th is a day celebrated by physicists and mathematicians the world over, especially on college campuses. March 14th is Albert Einstein's birthday. However, the tradition does not involve the eating of cake. Rather, people have noticed that 1:59 PM on that date, rendered numerically, is 3/14/159, which are the initial digits of the famed mathematical constant, $\pi = 3.1415926535\dots$. Thus, the traditional celebration is held at 1:59 PM and is marked by the eating of pie (apple, cherry, lemon meringue, etc.). The singing of Happy Birthday to Albert is optional. SPS chapters and student math clubs across the nation enjoyed the festivities this year. Here are few of their stories.

Pi in the Face

For the last three years, the SPS chapter at Northern Arizona University (NAU) has asked professors in the physics department to volunteer their faces for Pi Day. This celebration is a fundraiser and is open to anyone in the university who wants to throw a pie at a physics professor.

Says SPS president Linda Henneberg, "This was our third annual Pi Day, and our first year doing it jointly with the NAU Math Club. Pies were made out of chocolate pudding and whipped cream. The first pie, for the clean face, was auctioned off to the highest bidder, and subsequent pies were \$5. The first pie for one of the math professors went for \$54!"

This year the chapter joined forces with the Math Club and ended up making about \$200. Surprisingly, a lot of the money came from professors throwing pies at each other. Perhaps the stress of midterms takes a toll on professors as well?



NAU quantum professor, Dr. Dillingham, gets a pie in face.

Photo by Kathleen Stigmon

Let us know about your outreach and demonstration events! Email Kendra Rand, SPS Program Coordinator, at krand@aip.org.

Pi at the Mall

2 hours
6 tables of demos
200 pies
12 gallons of ice cream mix
40 liters of liquid nitrogen
And over 500 new Pi Day fans!

The Idaho State University (ISU) physics department and SPS chapter brought pie and physics to a local mall on Saturday, March 14.

"We bought 200 pies but ran out in about one hour. We made the ice cream mix the night before in milk jugs, enough for 12 gallons of ice cream. The ice cream lasted until 5:15 pm, so our last 45 minutes were without treats, but the demos and activities were very popular," according to Professor of Physics and SPS advisor Steve Shropshire.

The group's treats and assortment of demos and activities involving liquid nitrogen, electrostatics, and electromagnetism attracted over 500 people. The event even made the local TV news.

"The mall was very happy to have us and made every accommodation," said Shropshire. Why the mall? ISU's SPS chapter holds lots of popular science outreach events at the university such as the annual Haunted Science Lab. With Pi Day, they aimed to reach out to people that wouldn't usually come to the university, and it worked. They estimate that at least a quarter of the people that dropped by were just at the mall at the right time.

To get permission for Pi Day at Idaho's Pine Ridge Mall, ISU had to fill out an event request form and get approval from the corporate office. They also had to pay a \$50 facility use fee and sign a legal document accepting liability in case anything went wrong. If you're interested in holding a science outreach event at your local mall, start by contacting the mall manager.

If you do host an outreach event at a mall or other public location, be sure to go well prepared. "We planned on stuff breaking," said Shropshire, "so we brought spares of most of everything. Sure enough, one hand-cranked generator, one large tug-o-war electromagnet, and two 6 V flash-light bulbs were busted." Despite the challenges,



Students of ISU's physics department make themselves at home in the middle of Pine Ridge Mall.

Photo by Dayton Syme



Between five and seven SPS members were actively helping with the ISU Pi Day celebration at any given time.

Photo by Dayton Syme

public locations can offer unique opportunities for people to connect physics to real life. For instance, who knew a nearby candy machine could be a great ground for the Van de Graff human chain demonstration?

Pi at the SPS National Office

The SPS National Office is housed just outside Washington, DC, at the American Center for Physics, College Park, MD. The Center is the home of the American Association of Physicists in Medicine (AAPM), American Association of Physics Teachers (AAPT), American Institute of Physics (AIP), American Physical Society (APS), and Niels Bohr Library.

In honor of Pi Day 2009, the SPS staff and AIP's human resources department sponsored a Pi Party at 1:59 pm on Friday, March 13th. Yes, it was a day early, but not everyone works as much as physics students on the weekends.



Gary White, director of SPS, welcomes colleagues to the first annual Pi Day celebration at the American Center for Physics, College Park, MD.

Photo by Matthew Payne

Spotlight on SPS Outreach

Building Bridges and Dropping Eggs

By Dr. Chad A. Middleton, Assistant Professor of Physics & SPS Faculty Advisor at Mesa State College

On Saturday, April 25, the Mesa State College (MSC) chapter of the Society of Physics Students hosted its annual "Egg Drop and Bridge Building Competition." The competition, open to all local middle and high school students, involves designing and building a device that keeps an egg safe as it falls from the top of the MSC Library. The rules for the competition (no motorized parts, must be less than 5 pounds, and fit within a 2"x2"x2" box) are purposely left vague as our SPS club hopes to encourage creativity and ingenuity. The first prize of \$100 is awarded to the device that yields the shortest "flight time" from release to ground and contains an intact, undamaged egg after the drop. An auxiliary prize of \$50 is also awarded to the highly subjective "most aesthetically pleasing" egg drop contraption, as determined by our panel of judges. This year's winners included Francisco Vazquez of Central High School and Freddy Haun of Redlands Middle School.

Immediately following the egg drop, several middle school students competed in the bridge building competition. Armed with a "MacGyver kit" of popsicle sticks, super glue, duct tape, and rubber bands, the students set out to find who could build the strongest bridge in 45 minutes



If you drop the egg inside the chicken, will that keep it from breaking?

Photo by Christopher Tomlinson, Grand Junction Daily Sentinel. Used with permission.

time using only the previously named materials. The strongest bridge is determined by stacking masses onto the bridge's platform, in a successive series of one kilogram increments, until the bridge collapses under the added weight. This year's winner was Cody Mai, a home-schooled middle school student.

In addition to the competitions, SPS took the opportunity to showcase some physics demonstrations, including a bed of nails and a liquid nitrogen powered cannon, to the local youth. When asked why we take the time to host the event, SPS president Sherry Orton responded with "We here in the physics department know that science is super cool! I like to think that the egg drop and bridge building competition, not to mention our pumpkin drop held every Halloween, is an opportunity to convince the local youth of this seemingly obvious truth."

These events were funded in part by a 2009 Sigma Pi Sigma Chapter Project Award, which the MSC chapter of SPS was awarded.

SPS SOCK Celebrates International Year of Astronomy

Are you ready to get the ball rolling in your chapter's outreach efforts? Then set your sights on the 2009 SPS Outreach Catalyst Kit (SOCK)! The SOCK includes activities that reach from the heavens to homemade ramps, all based on work done by Galileo Galilei. The kit includes a variety of materials and ready-to-use lesson plans and demonstrations. Astronomical adventures include demos on topics such as crater formation and telescope observations. A special feature of the SOCK is a telescope of comparable power to that used by Galileo to study the night sky. Watch your email for instructions on how to get your paws on the new SOCK!



SPS Intern Mary Mills helps test some of the SOCK lessons on rolling objects with a class of 3rd graders.

Photo by Kendra Rand

Music, continued from page 8

Train "Drops of Jupiter" on *Drops of Jupiter* (Sony 69888). Uses image of Jupiter, Venus, and the Milky Way to talk about a girlfriend who had taken either a physical or a spiritual journey and was "back in the atmosphere" now.

Tyler, Bonnie "Total Eclipse of the Heart" on *Faster than the Speed of Night* (Sony 38710). 1983 hit song by a Welsh singer which uses eclipse images -- shadows, being in the dark, "no one in the universe as magical as you" -- to describe a love affair going wrong.

Waterboys "The Whole of the Moon" on *This is the Sea* (Capitol 21543). Interesting use of the image of the crescent moon versus the full moon as a way of expressing that the singer only saw and felt little, but his lover saw the larger emotional picture.

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2009 SPS intern Scott Stacey with an assembled Galileoscope.

Photo by Phillip Payette

SPS will be giving away Galileoscopes this fall—watch your email for details!

The Galileoscope is more than a telescope – it's a strategic initiative to improve math, science, and technology literacy worldwide. With this easy-to-assemble kit, anyone can explore how optics work and then go outside at night to see the celestial wonders first glimpsed by Galileo 400 years ago! For more information, visit <https://www.galileoscope.org>.