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The Magazine of the Society of Physics Students

Sometimes I Feel Like Quitting

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A Note About This Unusual Issue....

This issue of the Observer concerns itself with an unhappy subject. About mid-term every fall, a weight of discouragement descends heavily on many students. Frustration, unfulfilled expectations, gray skies, personal problems, being overwhelmed—all take their toll on our mental health. Many students suffer from depression. Every year about a dozen students in a hundred thousand will commit suicide. This reality lies just beneath the surface of every school year.

Some Facts About Student Depression and Suicide

Colleges and universities are starting to take more active roles than in the past, in meeting the mental health and emotional needs of students. The August 23, 2004, issue of Newsweek magazine (pages 59-60) carried a feature story called "Taking Depression On." According to the article, over 1,100 college students commit suicide each year. Some 40% of students report feeling "so depressed, it was difficult to function." Thirty percent report suffering from anxiety disorder or depression. Many colleges and universities are taking active steps to assist students through new attitudes, staff training, and proactive mental health resources.

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They've Been There: Boltzmann, Ehrenfest, and Pauli

In this issue we acknowledge a dark side of college and university life, student depression. It's a problem seldom acknowledged within the physics community. We do not know how to model or measure emotional problems; they do not answer to the tools of logic and reason. So we easily overlook them in others; and we internalize them in ourselves. This is corrosive. Good physics requires peace of mind. Peace of mind requires mental maintenance.

These afflictions of depression and, in some cases, suicide, have not spared some among our greatest physics heroes. Wolfgang Pauli suffered from frequent serious depression. So did Ludwig Boltzmann and Paul Ehrenfest. The Pauli Exclusion Principle, the Boltzmann formulation of Statistical Mechanics, and Ehrenfest's Theorem are among the greatest intellectual achievements in physics and are appreciated by all; yet their authors' personal struggles with depression took them to the pit of despair. Boltzmann and Ehrenfest, tragically, committed suicide. In studying the biographies of all three,[1-3] one can see in their lives several recurring themes: feelings of isolation, losses at vulnerable ages; unrealis-

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Sometimes I Feel Like Quitting

One Monday afternoon in October 1983, when I was a new assistant physics professor at Arizona State University, a young man entered my office. He spoke little but said that he was withdrawing from the university and therefore had to drop my introductory physics class. Thursday afternoon of that same week a young man committed suicide in the physics building. The building's fire escape, offset from the main building, is an eight-story tower whose winding stairs forms a rectangular shaft all the way from the basement to the roof. From the top landing, the student dove head first down the shaft, striking his head on the bannister on the second-floor landing. The ASU State Press reported that he had withdrawn from the university earlier that week.

When the campus police re-opened the stairwell, you could still see a few blood stains splattered high on the white painted concrete walls above the railing. At the roof landing, I found two dozen cigarette butts, every one smoked down to the filter and squashed flat. At the top of those stairs, feeling trapped, hopeless, and alone, the despondent student nervously smoked an entire pack, then made his final decision, leaned over the railing, and let go.

In any university the size of a small city (about 50,000 students were then at ASU), about half a dozen students kill themselves every academic year. Their pain becomes greater than their ability to cope. Feeling hopeless, they see no other way out. About mid-semester every fall, at least one student comes into my office and says, "I can't handle all of this, I want out." Since that Thursday in October 1983, I have always said to every such student, "If you need to bail out of my class, that's fine, but before I sign your with-

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Among this issue's other highlights:

- AAPM Summer Undergrad Fellowhip Program (pg. 4)
- Einstein's Quanta, Entropy, and the Photoelectric Effect (pg. 10)
- SPS Student Reporter at Summer 2004 AAPT Meeting (pg. 15)

SOMETIMES I FEEL LIKE QUITTING

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tic, obsessively high personal goals that set one up for the inevitable letdowns and frustrations.

Outworn heart, in a time outworn
Come clear of the nets of wrong and right;
Laugh, heart, again in the gray twilight,
Sigh, heart, again in the dew of the morn.[4]

When we struggle against depression, we feel isolated. We believe no one else could possibly understand. It may help all physics students struggling with depression today to know that some the greatest minds in our community carried its grim weight too. Despite the feeling that one bears the lonely weight of the world, we are *not* alone. We are harder on ourselves than are our friends and mentors. Would that Ludwig Boltzmann and Paul Ehrenfest had stayed the hand of suicide just one more day, one day at a time. Let's listen in...

Who would think that, only in 1900, people were battling, one might say to the death, over the issue whether atoms were real or not. The great philosopher Ernst Mach in Vienna said, No. The great chemist Wilhelm Ostwald said, No. And yet one man, at that critical turn of the century, stood up for the reality of atoms on fundamental grounds of theory. He was Ludwig Boltzmann, at whose memorial I pay homage.

Boltzmann was an irascible, extraordinary, difficult man, an early follower of Darwin, quarrelsome and delightful, and everything that a human being should be. The ascent of man teetered on a fine intellectual balance at that point, because had anti-atomic doctrines then really won the day, our advance would certainly have been set back by decades, and perhaps a hundred years. And not only in physics would it have been held back, but in biology, which is crucially dependent on that.

Did Boltzmann just argue? No, he lived and died that passion. In 1906, at the age of sixty-two, feeling isolated and defeated, at the very moment when atomic doctrine was going to win, he thought all was lost, and he committed suicide. What remains to commemorate him is his immortal formula,

$$S = k \log W$$

carved on his grave.[5]

Ehrenfest...obtained his doctorate from Vienna in 1904, under Boltzmann's supervision, on a topic in classical mechanics, the motion of rigid bodies in fluids and the mechanics of Hertz. It was considered a good piece of work but Ehrenfest never rated himself very highly and chose not to publish it after receiving his doctorate...

All through his life Ehrenfest had suffered from low self esteem, which was in marked contrast to the high esteem in which we has held by his fellow scientists. His last letter (which was never sent) is a sad document:

"I absolutely do not know any more how to carry further during the next few months the burden of my life which has become unbearable..."[3]

In a memorial essay, Albert Einstein said of his close friend,

To refuse to live out one's natural life because of inner conflicts that are felt to be intolerable—that is even today in persons of sound mind a rare occurrence... It is to such a tragic inner conflict that our friend Paul Ehrenfest has succumbed...

His stature lay in his unusually well developed faculty to grasp the essence of a theoretical notion...This capacity made him a peerless teacher....He fought against fuzziness and circumlocution, when necessary employing his sharp wit...Some of his utterances could have been interpreted almost as arrogant, yet his tragedy lay precisely in an almost morbid lack of self-confidence. He suffered incessantly from the fact that his critical faculties transcended his constructive capacities...

We whose lives have been enriched by the power and integrity of his spirit, the kindness and warmth of his rich mind, and not least his irrepressible humor and trenchant wit–we know how much his departure has impoverished us.[6]

Pauli loved people and showed great loyalty to his students and collaborators...It is true that sometimes he was a little hard to take, but all of us felt that he helped us to see our weaknesses....

Pauli mellowed much in his later years. This was mainly due to his second wife Franca, who was able to make his life bearable and even pleasant. This was not an easy task. Pauli had a very difficult character, was easily depressed and often felt thoroughly unhappy. Franca succeeded in creating a comfortable and protected home for him, in which we could feel at ease and pursue his many interests that reached far beyond physics...

He was not only a physicist, he was also a great personality, able to see deeper than others into scientific and human problems. The dark riddles of the human psyche were not unknown to him. He is an example to all of us of how to live a quiet and contemplative life of intellectual and moral integrity in these unruly times.[7]

One other recurring theme seems to emerge in the lives of Ludwig, Paul, and Wolfgang: although accustomed to dealing with reality when doing physics, they were unrealistically critical of themselves.

Weary of myself
What I am, and what I ought to be;
At this vessel's prow I stand, which bears me
Forwards, forwards. o'er the starlit sea.

And a look of passionate desire
O'er the sea and to the stars I send:
"Ye who from my childhood up have calmed me,
Calm me, ah, compose me to the end..."[8]

REFERENCES

[1] The School of Mathematics and Statistics, University of St. Andrews, Scotland, has assembled on a website a splendid collection of biographies of scientists and mathematicians. The biographies also contain references to more complete sources. The biography of Ludwig Boltzmann can be found at http://www-groups.dcs.st-and.uk/~history/Mathematicians/Boltzmann.html

[2] See http://www-groups.dcs.st-and.uk/~history/Mathematicians/Ehrenfest.html for the St. Andrews biography of Paul Ehrenfest.

[3] See http://www-groups.dcs.st-and.uk/~history/Mathematicians/Pauli.html for the St. Andrews biography of Wolfgang Pauli.

[4] First stanza of "Into the Twilight" by William Butler Yeats.

[5] Jacob Bronowski, *The Ascent of Man* (Little, Brown 1973), p. 351. Boltzmann's formula says that entropy S is proportional to the logarithm of the number of ways W of assembling the microscopic atoms into the macroscopic state. Today we call proportionality constant k "Boltzmann's constant." This insightful connection between the macroscopic and microscopic worlds open the window to the atom.

[6] A. Einstein, essay published first in Holland in 1934; reprinted as Essay 44 in *Out of My Later Years*, Citadel (1974), pp. 236-339.

[7] Victor F. Weisskopf, "Personal memories of Pauli," *Physics Today*, December 1985, pp. 36-41.

[8] First two stanzas of "Self-Dependence" by Matthew Arnold.

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Some Facts About Student Depression and Suicide

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The following are a few assorted notes gleaned from clinical textbooks and research reports. The causes of depression are complex and multi-dimensional. We refer you to the scholarly literature for details. We can also share in the experiences of other lives through great literature, as illustrated below.

The following statements are adapted from Chapter 15 of Psychiatric/Mental Health Nursing: Giving Emotional Care (2nd Ed.) by Ruth Beckmann Murray and M. Marilyn Wilson Huelskoeter (Appleton & Lange, 1987); from Chapter 10 of Psychiatric Nursing: Biological and Behavorial Concepts by Deborah Antai-Otong (Saunders, 1995); and Contemporary Psychiatric-Mental Health Nursing: The Brain-Behavior Connection by Carol A. Glod (Davis, 1998).

While some depression is occasionally experienced by practically everyone, serious depression is a recurring risk factor in all clinical accounts of suicide. Suicide becomes an option when a person's pain exceeds their ability and resources to cope with stress.

Depression can be defined as an emotional reaction, altered mood state, and complex of physical symptoms that are accompanied by negative self-concept and lowered self-esteem. It can be described as a period of intense sad mood, with disturbances in sleep, appetite and weight, energy, concentration, and physical activity. Depression is frequently seen as anger turned against self ("I'm to blame...I can't live up to expectations..." etc.)

Depressed adolescents may show irritable rather than down moods, and excess sleep and increased appetite instead of insomnia and appetite loss. Suicide, particularly impulsive acts, and drug or alcohol abuse are major risks.

For students, skipping classes, an unwillingness to engage in usual social activities, or lowering grades may be early signs of depression. Some may become isolated and withdrawn, and "fall between the cracks." Left untreated, early warning signs worsen and lead to depressive behaviors.

Symptoms include loss of interest in usual activities; feelings of helplessness and hopelessness; sleep disturbances; slowed body processes; feelings of worthlessness or guilt; fatigue, muscle aches; cognitive disturbances (as in the inability to solve physics problems that one knows how to solve); suicidal thoughts.

Feelings of hopelessness and despondency are central in most depressions, and are often triggered by perceived failure to attain some ideal.

Other patterns in some depression include over-reliance on a dominant other; a strong sense of duty; persistent feelings of guilt, however unjustified. The chronically depressed person is typically unable to develop deep relationships, has few gratifications, and feels constantly hopeless and empty. Sometimes these feelings are expressed in withdrawal, sarcasm, blaming, or criticism of self and others.

The depressed person typically exhibits inability to see the "big picture," focusing instead on negative details.

The loss to young children of a parent (through death or separation) creates a vulnerability to depression. Any major loss, such separation from a loved person, object, or status are common precipitants of depression. The loss may be real, such as health, finances, a beloved person, or a job; or it may be an imagined or symbolic loss. Loss for what was not achieved because of long-established high ideals and expectations of self are common initiators or accelerants of depression.

For some individuals depression can come in periodic cycles, some predictable; for example at certain times of the academic year when the stress piles up, demands become abundant, and rest and peace become scarce.

Depression is present in most persons who attempt suicide. Fifteen percent of persons diagnosed with depression attempt suicide. Some researchers note a genetic tendency to depression.

Suicide is always seen as a solution! Most often there is great ambivalence which may eventually lead to resolution through "settling" on suicide as the only tenable solution. Once that solution is made, there is relief; increase in energy and attempts to complete unfinished business.

Suicide can be defined as a direct, purposeful action taken by a person to end his or her own life. It is a growing problem in all societies, due to increased family disorganization, high family expectations, social stresses, and increased feelings of aloneness.

Suicide is the major leading cause of death for 10-to-24-year-olds. It is the leading cause of death among medical students, the second most common cause of death on college campuses, and the second highest cause of death (after accidents) among adolescents. In the United States, approximately ten people out of 100,000 take their lives in suicide annually.

Women attempt suicide two to three times as frequently as men; however men kill themselves more than women (see statistics below).

Myths and facts about suicide

(Adapted from "Suicide: A National Problem," Brown University, www.brown.edu/Administration/George_Street_Journal/v22/v22n6/sidebar.html; merged here with a similar list of "Myths and Facts" are found in Murray & Huelskoetter above.

Myth: People who talk about suicide don't follow through and kill themselves.
Fact: Eight out of ten people who kill themselves have spoken about their intent before committing suicide.

Myth: Asking a person if they feel suicidal will plant the idea of suicide in their head.
Fact: Talking about suicide does not make one more suicidal. But helping someone acknowledge their problems is the first step towards solving them. Your expression of concern might be their first hope that they're not facing their unhappiness alone. Talking about suicide or asking people about suicide is a relief to the suicidal person!

Myth: The stress of being a college student makes suicide more likely.
Fact: Studies show that suicide is less likely for students than for non-students of the same age and sex.

Myth: Being at prestigious schools makes suicide more likely.
Fact: Student suicide rates are independent of institutional prestige, size, or one's class standing.
(See also suicide statistics from "MIT Suicides Reflect National Trends," www-tech.mit.edu/V120/N6/comp6.6n.html)

Myth: A drunk person who talks about suicide need not be taken seriously.
Fact: Studies of student suicides show that over half of the students who committed suicide were intoxicated, most often by alcohol, and a slightly larger number may have had substance abuse problems.

Myth: Suicide happens without warning.
Fact: Although some suicides are impulsive, most suicidal persons give

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many hints and warnings regarding their intentions. (The suicide's friends and family are often plagued with guilt or remorse that they did not see the warning signs or take them seriously).

Myth: Once a person is suicidal, they are always suicidal.
Fact: Individuals who are suicidal wish to kill themselves for a limited time, usually in crisis. Their pain has exceeded their ability to cope with it. If they could get help through the crisis, help that follows through (see the next myth), they may put suicidal thoughts behind them.

Myth: Improvement following a suicidal crisis means that the suicidal risk is over.
Fact: Most suicides occur within about three months after the beginning of the "improvement." This occurs because the person has acquired the energy to put morbid thoughts and feelings and plans into effect.

Myth: All suicidal individuals are mentally ill; suicide is the act of a psychotic person.
Fact: Studies of hundreds of suicide notes indicate that although the person is extremely unhappy, he or she is usually not mentally ill. They are people in crisis who see no other way out. In their frame of mind suicide seems like the only escape, it's seen as the only rational choice open to them. They need help in seeing other options, the bigger picture.

From the aforementioned Brown University web site:

Suicide warning signs:
- A previous suicide attempt
- Talking about suicide
- Deep depression
- Changes in behavior and personality
- Giving away favorite possessions
- Drug or alcohol abuse
- Feelings of hopelessness or helplessness
- Loss of interest in friends or hobbies

To the above list of suicide risk factors the website of the National Center for Injury Prevention and Control, www.cdc/gov/ncipc/factsheets/suifacts.htm adds several more, including the following:
- Unwillingness to seek help because of stigma attached
- Local epidemics of suicide
- Loss
- Isolation, a feeling of being cut off from other people
- Family history of suicide or child maltreatment
- Easy access to lethal methods

NCIP also lists "protective factors" that "buffer people from the risks associated with suicide:"
- Effective clinical care for mental, physical, and substance abuse disorders
- Easy access to a variety of clinical interventions and support for those seeking help
- Family and community support
- Developing skills in problem solving, conflict resolution, and nonviolent handling of disputes
- Cultural and religious beliefs that discourage suicide and encourage self-preservation instincts

Acknowledgement
I wish to thank Philip Budd, Psy.D., Director of Graduate Programs in Counseling, Southern Nazarene University, for lending his expertise and making helpful suggestions.—Ed.

Suicide statistics

(from the National Center for Health Statistics, http://www.cdc.gov/nchs/fastats/sucide/htm)

All suicides (USA, 2001): 30,622
Suicides per 100,000 general population: 10.8 (in 2001)
Death rates for suicide, per 100,000:
All persons: 15-25 years, 9.9; 15-19 years, 7.9; 20-24 years, 12.0
Men: 15-24 years, 16.6; 15-19 years, 12.9; 20-24 years, 20.5
Women: 15-24 years, 16.6; 15-19 years, 2.7; 20-24 years, 3.1

Other Lives

To understand the human condition intimately, beyond one's own experience one can do no better than live other lives vicariously through great literature. If you would seek to enter a mind driven to suicidal thoughts, read Anna Karenina by Leo Tolstoy. Empathize there with the pain of a life's mistake, the bitter disappointment that ensued, mental turmoil that grew out of control in a perfectly sane person. If you have not yet read Anna Karenina I won't tell you how it ends. Let us instead enter the mind of Inspector Javert, from Victor Hugo's Les Miserables.

Javert's rigid certainties about law and punishment were ripped to shreds after Jean Valjean, the old convict, stepped outside the law and showed the Javert mercy at the barricade. Jean Valjean, released the captured Javert instead of blowing the Inspector's brains out with a pistol as the revolutionaries had ordered. Javert found himself in despair over a real question which had overwhelmed him. Javert could not live up to his unrealistic idealizations. They finally failed him, leaving him desolate:

...A single resource remained: to return immediately to the Rue de l'Homme Armé, and have Jean Valjean arrested. It was clear that was what he must do. He could not.

Something barred the way to him on that side.

Something? What? Is there anything else in the world besides tribunals, sentences, police, and authority? Javert's ideas were overturned...

Javert's ideal was not to be humane, not to be great, not to be sublime; it was to be irreproachable. Now he had just failed...

He saw what he revolted at seeing. He felt that he was emptied, useless, broken off from his past life, destitute, dissolved. Authority was dead in him. He had no further reason for existence....

Unnatural state, if ever there was one. There were only two ways to get out of it. One, to go resolutely to Jean Valjean, and to return the man of the galleys to the dungeon. The other—

...The place where Javert was leaning was, it will be remembered,

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situated exactly over the rapids of the Seine, perpendicularly over that formidable whirlpool which knots and unknots itself like an endless screw.

Javert bent his head and looked. All was black...He saw nothing, but he perceived the hostile chill of the water, and the insipid odor of the moist stones. A fierce breath rose from that abyss. The swollen river guessed at rather than perceived, the tragical whispering of the flood,... the imaginable fall into that gloomy void, all that shadow was full of horror.

Javert remained for some minutes motionless, gazing into that opening of darkness; he contemplated the invisible with a fixedness which resembled attention. The water gurgled. Suddenly he took off his hat and laid it on the edge of the quai. A moment afterward, a tall and black form, which from a distance some belated passer might have taken for a phantom, appeared standing on the parapet, bent toward the Seine, then sprang up, and fell straight into the darkness; there was a dull splash; and the shadow alone was in the secret of the convulsions of that obscure form which had disappeared under the water. ◆

The Longer View

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focused on the insignificant *ten-point problem* of today that I took my eyes off the larger goal of maintaining the peace of mind that would enable me to finish the *degree*. The clinical textbooks say that an unwarranted exaggeration of small difficulties, while forgetting the big picture, falls among the symptoms of depression. Hmm, that hits pretty close to home. In that case, so be it: it's part of who I am. With hindsight, I can now see that dealing with these things with the help of others, forms a rich part of being a human being.

Remembering the larger mission sometimes means letting a ten-point problem go. Let it go. *Let it go*. Remember the mission. What will matter ten years from now? Go hiking with your friends. You will remember their laughter and the sunshine and the mountains long after you have forgotten the small task that was left undone.

But even if you and I give it our best shot and we still fail at physics, *so what*? If they throw us out, we'll go to Montana and raise horses. Or we'll move to Taos and take up sculpture, or the Ozarks and start a coffee house with banjo players on the deck out back and we'll take long motorcycle trips during the fall.... It's a big world out there. But what a ride, eh?

Dedicated to the memory of Wanda,
Who seemed to have everything
But peace of mind
Wish you were here

— Dwight E. Neuenschwander
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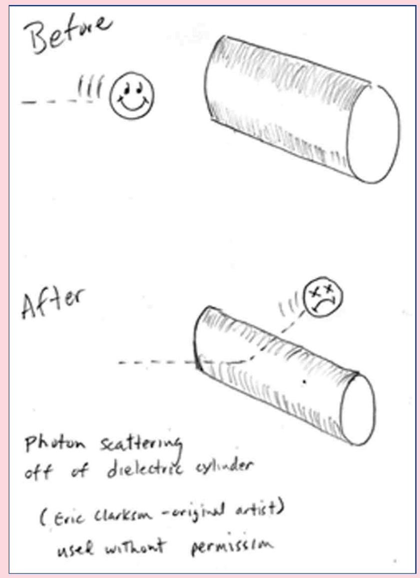

Eric's "solution."

AAPM Summer Undergraduate Fellowship Program Update

— *By George Sandison, AAPM*

The aim of the 10-week AAPM Summer Undergraduate Fellowship Program was to expose fellows to medical physics research and clinical practice and so influence them to undertake medical physics graduate study. The recent competition for a fellowship was very strong. Sixty-seven students applied and the ten winners had an average GPA of 3.86! Part of the formula for success in attracting this large pool of outstanding students was the program's advertisement in the *SPS Observer*. Below are some of the summer 2004 highlights for a few selected fellows.

Nyimas Arief
(Mentor Dr. Paul Keall, Virginia Commonwealth University)

The goal of this project was to determine the feasibility of a prototype three-dimensional wedge which aims to improve homogeneity of dose treatment in radiation therapy for whole brain radiation therapy. Nyimas' major task was to analyze the data to see whether the wedge improves dose uniformity during treatment. She is seriously considering a career in medical research and bioengineering.

Courtney Buckey
(Mentor Dr. F. Chris Deibel, Cleveland Clinic Foundation)

Courtney measured beam data for four linear accelerators for use in the Clinic's new treatment planning computer. She also received experience with conventional external beam planning, IMRT, and both HDR brachytherapy and intra-operative brachytherapy. She was involved in treatment planning for a Radiation Therapy Oncology Group study, in performing monthly and annual quality assurance checks on linear accelerators, and in observing and assisting patient treatment at the Gamma Knife Center. Courtney was awarded a travel grant from the Penn-Ohio chapter of the AAPM to attend the Annual Meeting in Pittsburgh.

Christopher Danford
(Mentor Dr. John Humm, Memorial Sloan-Kettering Cancer Center)

Chris worked on a project bridging PET molecular imaging with IMRT. PET was used to examine the degree to which regions of tumor hypoxia remain static over and

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drawal form I must know what's going on in your life, and I must know where you are jumping to." It *is* my business. At least one of several themes invariably surfaces in these interviews. Fear of failure. Feeling overwhelmed and discouraged and trapped. Unable to measure up to one's own expectations—or someone else's. If you have been in college at least half a semester, some of this may sound familiar.

Faculty members sometimes feel like quitting too. Most days we respond with joy to the challenges of sharing our discipline with enthusiastic young people. We are doing work we love, and sharing the adventure with you keeps us young at heart. But later in the semester, we sometimes feel overwhelmed by the endless grind of grading papers that all sound alike, by the inability to break through the apathy of a captive audience, and by fear that the future is looking more and more like the past. When we were students ourselves, we felt like quitting back then too, many times. We've been there. Each faculty member can tell his or her personal stories, from the past and present, about discouragement and persistence.

Partly from enthusiasm and partly from fear, during my first semester in graduate school in Arizona, I assumed the way to excel at this new level was to maximize the time spent in the office. I slipped into the mindset of the recluse, a form of self-centeredness based on unrealistic expectations. The distance between myself and the people around me increased as the office walls closed in. You know what happened next. A downward spiral of burnout played itself out. Some nights I went into restless sleep heartily wishing that I would never wake up. Work that could not be completed in the week was dumped into the weekends. The weekends started with a splitting headache, inability to focus, resulting to my facing the next week farther behind and more exhausted. Not good maintenance of the mind. Frustrated without understanding why, after three semesters I transferred to another university, in Kansas. I soon discovered that, alas, I had brought myself along. By the end of one semester and a summer I finally realized the problem was internal. That August, on the second day of a semester for which I could not bring myself to register, I packed up and walked out. Not caring if I was committing professional suicide, I dropped out of grad school for a year. That December I read *A Christmas Carol* by Charles Dickens. The ghost of Jacob Marley appeared to Ebenezer Scrooge, but he spoke to me:

...The chain he drew was clasped about his middle...it was made of cashboxes, keys, padlocks, ledgers, deeds, and heavy purses wrought in steel...

"I wear the chain I forged in life," said the Ghost.... Is its pattern strange to you?... Oh! Captive, bound, and double-ironed," cried the Phantom,...

"Not to know that any Christian spirit working kindly in its little sphere, whatever it may be, will find its mortal life too short for its vast means of usefulness...Yet such was I! Oh! Such was I!"

"But you were always a good man of business, Jacob," faltered Scrooge, who now began to apply this to himself.

"Business!" cried the Ghost, wringing its hands again. "Mankind was my business. The common welfare was my business; charity, mercy, forbearance, and benevolence, were, all, my business. The dealings of my trade were but a drop of water in the comprehensive ocean of my business!"

That year of reflection turned out to be time well spent. It helped me gain a larger perspective and distinguish long-term mission from short-term means. I had to be reminded the hard way that I had been doing it all backwards. Good physics requires peace of mind. Peace of mind is held together by taking some time for mental maintenance. Peace of mind is sustained by caring personal relationships. This student re-reads *A Christmas Carol* every December. It's a personal tradition.

After a year I returned to my original graduate school, back in Arizona. The Kansas faculty were gracious, but I felt should finish where I started. This time I made the conscious decision to enter the lives of the people around me, both inside and outside the university. The first time, I was going to graduate school, which happened to be located in Arizona. The second time, I was going to live in Arizona, and while there would finish graduate school. The difference in emphasis was transforming.

In school I made some useful mistakes. I am thankful for them now. I can empathize with my students who are despondent. When you're despondent it's usually not a single thing that does it, but lots of 'em; they seem to pile up on you until one day you say "I've had it, screw this place, I'm outta here." The stairwell then holds its immediate attraction. But if before diving one can glimpse the larger view, one realizes that it's a big world out there, somebody somewhere really cares, and one really does have options. When I decided that doing physics was an important part of who I am, I went back to graduate school but this time I had come to an understanding with myself: "I'm going to do the best I can with what I have, but one of two results are going to happen: Either they will award me that diploma, OR they will have to throw me out the front door. But I'm not going to *take myself out*." They never got around to throwing me out, so eventually I finished the PhD. Getting through college or graduate school is mostly about persistence, but persistence tempered with good maintenance.

For an after-dinner speech during the banquet of an international conference in 1975, physicist Frederick Reines composed a poem that described the research problems then facing physics. The opening lines of Reines' ode are highly transferable to other missions and lives:

If at first you don't succeed
What did you expect?
Progress would be slow indeed
With nothing to reject.

A false step here, another there,
It means you're really trying.
Besides, the struggle up the stair
Itself is satisfying....

In the university you receive two educations. One is the acquisition of proficiency in an academic major. But the second and more important education comes in what you learn

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Jacob Marley's ghost appears to Ebenezer Scrooge in A Christmas Carol, written by Charles Dickens. Photo credit:

PHYSICS NEWS UPDATE

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— by Phillip F. Schewe and Ben Stein

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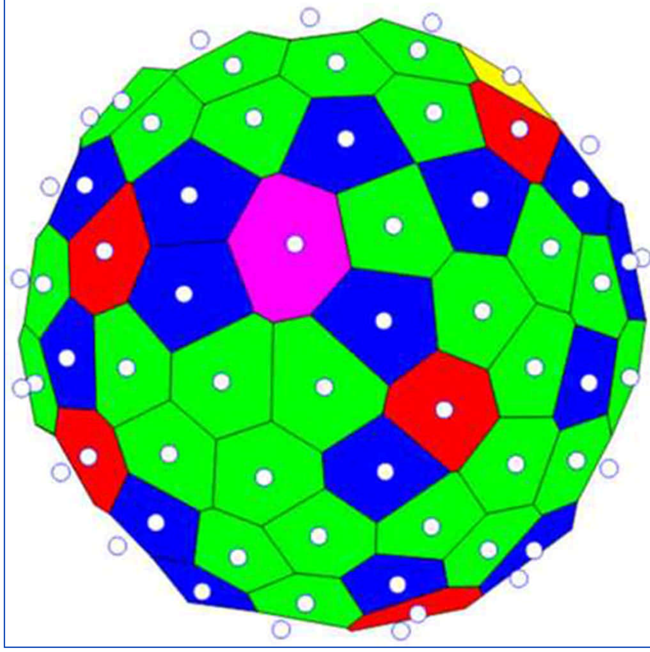
CRYSTALLINE ORDER AT 40,000 K. Physicists at the Christian-Albrechts Universität in Kiel and Ernst-Moritz-Arndt Universität in Greifswald (Germany) have been able to rig a ball of dust particles holding to a crystalline structure even in the middle of a hot plasma. Most crystals—that is, solid materials in which atoms are arrayed in a regular stacked-cannonball order—melt at temperatures of hundreds or thousands of degrees. The heartiest crystal, diamond, succumbs at 4000 K. The heat is just too much for the atomic bonds and the defining grid-iron structure weakens and melts. Another sort of "crystal," at low temperatures, is the optical crystal consisting of an artificial and diffuse array of atoms held at the interstices of a 3-dimensional lattice by the electric fields of cross-cutting laser beams. The plasma crystal, by great contrast, consists of a herd of charged 3.5-micron-sized polymer particles amidst a gas-discharge. Juggling two mighty forces—the mutual repulsion of the particles among themselves and the compressive force on them by the surrounding plasma—the particles manage to arrange themselves into neat concentric spheres, to a total ball diameter of several mm (see figure at right). It is ironic that J. J. Thomson, the discoverer of the electron, had suggested in 1904 that the layout of the Periodic Table of elements could be explained if atoms had exactly this sort of onionlike architecture, with negative charges held poised in a wider sea of positive charges. This idea was wrong for atoms but does describe the arrangement of the dust particles in this plasma. To sum up: in a plasma where the electron temperature is 40,000 K (the positive-ion temperature is less than 1000 K), an orderly Coulomb ball consisting of aligned, concentric shells of dust particles can survive for long periods. The two outstanding features of the ball (other than its survival at such high temperatures) are that it represents a true transparent crystal; with a microscope and video camera individual particles in the middle of the structure can be imaged by laser light. The other feature is the slowness of the dynamics. The particles move about with a characteristic timescale of milliseconds rather than the femtosecond scale of atoms in a conventional crystal. The study of laboratory plasma crystals, the experimenters believe, gives fundamental insight into strongly coupled matter and applies directly to the study of intergalactic nebulae, comet tails, the rings of Saturn and, back here on Earth, in the improvement of various microchip processing steps. (Oliver Arp et al., *Physical Review Letters*, upcoming article.)

Dust Crystal at 40,000 K



The bottom side of the outer shell of a "Coulomb ball," a formation of dust particles that keep to a crystal-like structure even in the middle of a plasma where the electron temperature is 40,000 K. The particle positions are marked by dots. The number of neighboring particles is indicated by the colored cells (5=blue, 6=green, 7=red) . To form a spherical surface with a regular close packing of particles mainly hexagons (green) and a few pentagons (blue) are needed. This is the same principle as covering a soccer ball with hexagon and pentagon leather patches.
Reported by: Arp et al., Physical Review Letters, 15 October 2004

ATOMS CAN TRANSFER THEIR INTERNAL "STRESS" TO OTHER ATOMS, new experiments have revealed. Compared to atoms that are all by themselves, atoms with a close neighbor have a very efficient and surprising way to get rid of excess internal energy. An excited atom can hand over its energy to a neighbor, a research team led by the University of Frankfurt has demonstrated experimentally in a measurement carried out at the Berlin synchrotron facility BESSY II (R. Doerner). Predicted in 1997 by a group at Heidelberg University (Cederbaum et al., *Phys Rev. Lett*, 15 Dec 1997), this decay mechanism occurs when atoms or molecules lump together. Once an excited particle is placed in an environment of other particles such as in clusters or fluids, the novel de-excitation mechanism, called "Interatomic Coulombic Decay," leads to the emission of very low-energy electrons from a particle that is neighboring the initially excited one. The researchers demonstrated the effect in a pair of weakly bound neon atoms. The two neon atoms were separated by 3.4 Angstroms (about 6 times the radius of the neon atom) and held together by a weak "van der Waals" bond. Removing a tightly bound electron from one of the neon atoms allowed one of the less tightly bound atoms to jump down to the tightly bound spot and in the process gained energy. The extra energy was not sufficient to liberate any of the remaining electrons in the same neon atom, but it was sufficient to release an electron in the neighboring atom. This newly verified effect may have a wide-ranging impact in chemistry and biology since it is predicted to happen frequently in most hydrogen-bonded systems, most prominently liquid water. Furthermore, it may be an important, and so far unknown, source of low-energy electrons, which have recently been shown to cause damage to DNA. (Jahnke et al., *Physical Review Letters*, 15 October 2004.)

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Physics News Update (continued from page 8)

Number 702 September 28, 2004

TWENTY MILLION AMPS OF CURRENT, released from a bank of capacitors over 100 nsec and sent into a cage of wires, is converted at Sandia's Z facility into 1.8 mega-joules of soft-x-ray energy, with a peak power of 200 tera-watts. Thus the Z machine is the highest peak-current pulsed-power device in the world (over nanosecond timescales), and the most potent source of soft x rays (radiation in the 100-10,000 eV range). The total x-ray energy conversion fraction—utility power turned into x rays—is 10 to 15 per cent, much higher than for any other x-ray source. This makes the Z machine potentially useful for studying two important transactions: nuclear fusion reactions, maybe for producing commercial power; and the radiation spewing out of nuclear bombs. Owing to treaties, the physics of nuclear weapons cannot be studied directly by explosions but only indirectly by tests such as those at Sandia National Lab with its Z machine. The newest development in this subject is Sandia's ability to photograph the sequence in which the tiny array of wires carrying the stupendous mega-amp current implodes (the vaporizing wires are pinched inwards by a huge magnetic field) and forms an x-ray-emitting plasma. The first surprise, once the dynamics of the event could be unfolded from data recorded with special crystals, was how long the pinched wires survived the ordeal. The series of photos, taken using a separate (weaker) x-ray source to backlight the interaction zone, should allow the Sandia researchers to optimize their wire-array design in order to produce even greater x-ray yields. (Sinars et al., *Physical Review Letters*, 1 October 2004.)

RED NUCLEI. Experiments conducted in Oslo and Budapest have determined that the gamma rays streaming out of excited iron nuclei come in all different energies—relatively low energy (3 MeV) as well as the expected higher energy (10 MeV). In other words, the nuclei proved to be (if one can impute colors to the gamma spectrum equivalent to the visible spectrum) "redder" than thought. Why is this a surprise? First of all, knowledge of energy levels in the nuclear realm is not nearly as detailed as it is for atoms. Quantum electrodynamics (QED), the theory which rules the atomic world, can specify energy levels with uncertainties in parts per trillion. By contrast, quantum chromodynamics (QCD), the theory that attempts to grapple with the strong nuclear force, is rather vague, a shortcoming owing chiefly to the strength of the nuclear force. The best predictions of energy levels, in some nuclei, are only good to about 10 per cent. Not only that, but when a nucleus such as iron is "heated" (via particle interactions) through a "temperature" corresponding to 1 MeV, thousands of higher energy levels can be populated. When researchers observe the subsequent cooling of such nuclei what they see is not the spectrum of discrete lines one gets with atoms but instead a quasi-continuum of gamma lines. According to Andreas Schiller of Michigan State University, the unexpected red gamma rays might correspond to the excitation energy of some new robust, collective, low-frequency oscillation in the iron nucleus. The collaboration includes scientists from the Joint Institute of Nuclear Research (Russia), the University of Oslo (Norway), Chemical Research Centre (Hungary), Osmangazi University (Turkey), and several US institutions—Ohio University, Lawrence Livermore National Lab, North Carolina State, and MSU. (Voinov et al., *Physical Review Letters*, 1 October 2004.)

THE HELIUM-SIX NUCLEUS consists of a He-4 nucleus (two protons plus two neutrons) surrounded by a halo cloud consisting of two more neutrons. The charge radius for He-6 has been now measured for the first time. The experimental value, 2.1 fm (2.1 x 10^{-15} m), is larger than the radius for He-4, 1.7 fm, the reason being that the halo neutrons in He-6 cause the core portion of the nucleus to inflate somewhat (see figure at right). The He-6 nuclei are made at a special beamline at Argonne National Lab by smashing a beam of lithium ions into a target. The stray He-6 atoms made in the process (about a million per second) are drawn into and lodged within a trap at a rate of about one a minute. This is sufficient to do laser spectroscopy on the atoms. The charge radius of the nucleus can be deduced from the way in which the frequency of the light corresponding to an internal atomic transition from one quantum state to another in the atoms is shifted in going from He-6 to He-4. Zheng-Tian Lu of Argonne says that He-6 is the lightest known nucleus to have a neutron halo, and that the collaboration's next experimental quarry, He-8, represents the most neutron-rich (highest neutron-to-proton ratio) nuclear matter in the world. (Wang et al., *Physical Review Letters*, 1 October 2004.)

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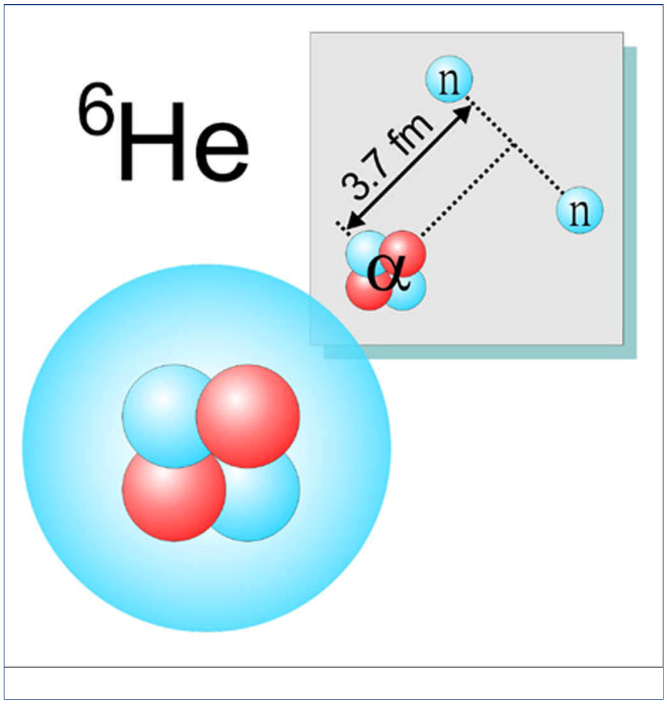

Shown: Helium-6 nuclei are thought to consist of a helium-4 inner part (denoted by two neutrons and two protons) and an outer "halo" part consisting of two more neutrons.

Reported by: Wang et al., Physical Review Letters, 1 October 2004.

Sometimes I Feel Like Quitting

(continued from page 3)

about yourself, such as: Don't sweat the small stuff. Most things you fuss over today won't matter 10 years from now. You discover that getting into things is easier than getting out of them. But you also learn that if you are bold then mighty forces will come to your aid. You learn that Life is what happens to you while you are busy making other plans. You learn to not let the destination of tomorrow rob you of the ability to cherish the journey of today. You learn that obsession with Perfection leads to frustration; instead, strive for Excellence, for it leads upward through great adventures. You learn that people are more important than professions, and that grace comes through personal relationships. And if you learn to laugh often, especially at yourself, you discover to your delight that comedy is all around you.

It's very easy for me to take myself way too seriously; that is my temperament. Over my desk I display a print of *The Repentant Magdalene* by Georges de La Tour, and *Woman Holding a Balance* by Johannes Vermeer. There is profound wisdom in these serious paintings, calling us to the finiteness of life and its consequences. But I also keep over my desk a photo of three philosophers. They are my three favorite philosophers. Their names are Larry, Moe, and Curly. They help me keep everything in perspective. There is profound wisdom in their merriment.

To you and me both I say, Let's keep hanging in there. The stairwell is never the answer. Life, including life in a university, is far too interesting and funny and important to be taken too seriously.

"The Repentant Magdalene," c. 1640, Georges de La Tour (1593-1652) National Gallery of Art, Washington, DC.

A portion of this article was adapted from the author's "Conversations with Ghosts," *Am. J. Phys*., March 2001 (251-254). The Reines poem was delivered at an International Conference on Neutrinos. Reines is a co-discoverer of the neutrino. *A Christmas Carol* was first published in 1843.

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PS: The Longer View

If I may solicit the reader's indulgence, I shall tell a little story on myself, about one of my less-than-ideal weekends during my first year in graduate school. This story is offered in the hope that a student for whom the following scenario sounds familiar will learn from the mistakes of a kindred spirit.

I was sharing an apartment with two other first-year physics grad students, John and Eric. The three of us were taking Classical Electrodynamics together. In our homework assignment one week was a problem of light scattering off a dielectric cylinder. Having struggled with that problem all week, I found myself royally stuck. The weekend promised ample time, surely, to finish it off. That task, along with several others that had piled up throughout a hectic week, were being dumped into Saturday and Sunday.

Saturday morning dawned golden and blue, with bright promise of a glorious Arizona day. This was Tempe, AZ, in February. That meant clear skies, refreshingly cool temperatures, and a day of your life perfect to spend outdoors. John and Eric decided to go hiking in the Superstition Mountains east of Phoenix. They invited me to come along.

No, I said, I had some physics homework to do. They left. I stayed in my room all that day, despite the sunshine and palm trees, a self-imposed isolation. For all the good that choice did I might as well have spent the day beating my head against the wall. The longer I sat at my desk, the less I could work that problem. The less I could work that problem, the more stubbornly I sat at my desk. As you might expect, I worked myself up into a fine frenzy of frustration, with a splitting headache to boot. Late that afternoon John and Eric returned, slightly sunburned, but bubbling over with exuberance from a day well spent in the mountains. My outlook was dark and black, the day utterly wasted. Not only was the problem still unsolved, but the time was gone, and opportunity for doing something I love and doing it with friends was thrown away. I went through the rest of the weekend discouraged, and angry with myself and with life in general. John and Eric were able to start the next week refreshed. I started it exhausted and frustrated.

Well guess what. Even though I did not solve that scattering problem, I had to grade it the next week! Our professor's policy had us grading one another's homework, and I it fell to me to grade that very problem of light scattering off the dielectric cylinder! Under the circumstances I began with the solution written by the student who seemed to work every problem effortlessly; it was, naturally, straightforward enough, which only added to my feelings of inadequacy and despair. Maybe I should quit. Maybe I'm not good enough. Maybe I should....

Then in the stack of papers I came across Eric's "solution."

I use the term loosely. However, under the circumstance, it was perfect (see my rendition of it on page 7). I laughed, and wearing my grader's hat awarded him fifteen virtual points (ten plus five bonus). Then I also had to laugh, somewhat bitterly, at myself. For even though Eric had not worked the problem either, he cut his losses, refusing to throw good time after bad. Eric had enjoyed a great day that Saturday, and because he deliberately took time *not* to study he faced the challenges of the new week refreshed. He managed his peace of mind intelligently, which was far more important than that damn problem. When push comes to shove, it's peace of mind that will get you through, not carving notches on your physics book.

The true philosopher takes wisdom wherever it may be found, even from one's quiet roommate who has a dry but healthy sense of humor. That experience was but one installment in a series of lessons (I'm a slow learner in these things), on distinguishing strategy from tactics in navigating the emotional ups and downs of getting through school—and through life. I had become so stubbornly

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SPS Student Reporter Writes Up the Summer 2004 AAPT Meeting at Sacramento, CA

— By Paul Charles Whitford, University of California-San Diego

Excitement might not be the first word that comes to mind at the mention of an AAPT meeting. The name, American Association of Physics Teachers (AAPT), may give the impression that the crowd won't be too lively. However, nothing could be further from the truth. To get an idea of who is there, first think of the most energetic, fun and enthusiastic professor you ever had. Take several hundred people just like that, from across the nation, and you have the makings of an AAPT meeting. AAPT meetings provide an excellent opportunity to meet these interesting people and to both present your ideas and learn from others on everything education-related, from Women in Physics to Teaching Physics in Africa.

Gary White, SPS and Sigma Pi Sigma Director, talks with SPS members during a break in the meeting.

With the meeting as full of exceptionally personable physicists as the ground state of a Bose-Einstein condensate, the opportunity to network is remarkable. Besides getting to hang out with Gary White, Director of SPS, we met some of our nation's most acclaimed teachers including the AAPT President Elect, Richard Peterson. We also hung out with a group of physics education researchers, including Noah Finkelstein and our own Ed Price, who were full of fire and fun. Noah, now at UC Boulder, was once a graduate student at UCSD and was able to give valuable advice concerning an outreach project which is being revived here in San Diego, CA, in which graduates and undergrads team up with middle school students to help with physics projects for the regional science and engineering fair.

Let's not forget this is a professional meeting, which means there are opportunities to present work, including sessions specifically for students. In addition to reporting for SPS, we presented a poster at the SPS poster session. Our presentation was about the PMUG (Physics Majors User's Guide) program at UCSD, in which graduate students mentor undergraduates in some of the out-of-class aspects of physics. If you are interested in presenting your work, or would just like to go to an AAPT meeting to be a reporter, SPS often helps fund students' travel to the event, so look into it!

Not only do you get to see PER research; there are sessions geared at every aspect of physics education. Two of our favorite sessions were "Teaching Physics in Africa" and "Public Outreach Activities of the World Year of Physics 2005." If you have ever considered teaching in a third world country, what can be better than being in a room with 20 people who already have? We were able to hear first hand what the day-to-day life is like in these countries, what kind of challenges there are, and what we can do to improve the situation. As far as 2005 goes, every physicist needs to know that it's **THE WORLD YEAR OF PHYSICS** and get pumped up for it. This session included spokespeople from the American Physical Society (APS), SPS, American Institute of Physics (AIP), the Einstein Experts, the AAPT—of course—and even the Swedish laser-meister Per Olof Zetterberg. If you're not ready for The World Year Of Physics, then you didn't attend this session; but it's not too late. Go to the Winter 2005 meeting in Albuquerque, NM.

The three days we were at the conference were busy all the way to the last half hour, when we had the chance to sit down with AAPT President-Elect, Richard Peterson, of Bethel College, and learn about how he became involved in AAPT. Neither a physics education researcher nor a gung-ho lecturer, Richard got his start in AAPT back in graduate school when he caught wind of the apparatus competition AAPT was having. Being an experimental optical physicist, he couldn't resist joining in, and the rest is history.

In closing, the Summer 2004 AAPT Meeting at CSU Sacramento was an opportunity to learn about an enormous range of physics education-related topics; to share our PMUG work with others; and to interact—formally and informally—with scores of friendly, enthusiastic, and dedicated physics education researchers and teachers.

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SPS members Stacy Elizabeth Sude, James Hitchcock, Maire Daley, and Louise Riofrio, hold certificates for their presentations at the Summer 2004 AAPT Meeting.

ELEGANT CONNECTIONS IN PHYSICS

Einstein's Quanta, Entropy, and the Photoelectric Effect

— *by Dwight E. Neuenschwander*

"On a Heuristic Point of View Concerning the Production and Transformation of Light"[1] was the first of the five papers published by Albert Einstein in his 1905 "miraculous year."[2] In that paper, Einstein introduced the concept of "light quanta," or "photons" as we call them today.

The quantum of action was introduced into physics by Max Planck in 1900.[3] Planck derived the thermal equilibrium energy distribution for electromagnetic radiation (also called "blackbody problem" because of the experimental apparatus). The quantity of interest was *d*r/*df* where r denotes the energy density and *f* the frequency (Fig. 1). No one had been able to derive *d*r/*df* from the first principles of statistical mechanics. One serious problem was in the high frequencies, which contributed infinite energy when one integrated over all frequencies to obtain the total energy!

Planck thought about the charged particles whose simple harmonic motion generated harmonic electromagnetic waves of the same frequency. Planck discovered that if he assumed a particle oscillating with frequency *f* could carry only the discrete energies 0, *hf*, 2*hf*, 3*hf*..., where *h* was a constant, he could derive the distribution function:

$$d\rho/df = (8\pi h/c^3)\, f^{\,3}\, (e^{hf/kT} - 1)^{-1}\ ,$$

where *c* denotes the speed of light in vacuum, *k* Boltzmann's constant, and *T* the absolute temperature. This function fit the data provided *h* was assigned the value 6.6×19^{-34} J · s, now called Planck's constant.[4] The smallness of *h* accounted for the lack of energy graininess in macroscopic oscillators such as pendulums.

To Planck in 1900, the quantum was a property of the *mechanical oscillators* that happen to generate light. Radiation itself, in principle, would still be described by continuous functions, as Maxwell's equations assume. In 1905 Einstein greatly enlarged Planck's concept. To Einstein, *light itself* was quantized into little pellets of energy. *This was revolutionary.* Where Planck saw the quantum as a calculation device to solve a particular problem, Einstein saw the quantum as fundamental.

As in so many of his papers, Einstein began by critiquing a lack of consistency in the accepted network of concepts. Physicists had started to realize that treating matter as continuous was only an approximation, valid when the size scale was an average over huge numbers of atoms. But at the microscopic level, matter was starting to be recognized as quantized; the charge-to-mass ratio of the electron was measured in 1897. Yet physicists continued to treat electromagnetic fields as continuous functions. Why should matter be discrete but radiation continuous? Einstein questioned this assumption by introducing his 1905 paper with these words:[4]

A profound formal difference exists between the theoretical concepts that physicists have formed about gases and other ponderable bodies, and Maxwell's theory of electromagnetic processes in so-called empty space. While we consider the state of a body to be completely determined by the positions and velocities of an indeed very large yet finite number of atoms and electrons, we make use of continuous spatial functions to determine the electromagnetic state of a volume of space, so that a finite number of quantities cannot be considered as sufficient for the complete determination of the electromagnetic state of space. According to Maxwell's theory, energy is considered to be a continuous spatial function for all purely electromagnetic phenomena, hence also for light, whereas according to the present view of physicists, the energy of a ponderable body should be represented as a sum over the atoms and electrons. The energy of a ponderable body cannot be broken up into arbitrarily many, arbitrarily small parts, but according to Maxwell's theory (or, more generally, according to any wave theory) the energy of a light ray emitted by a point source continuously spreads out over an ever-increasing volume.

This was a brazen challenge to a debate that had been thought settled for a century. In the days of Newton, Hooke, and Huygens, the question of *what light is* stirred controversy. The battle was carried under the flags of "particles" and "waves." They form orthogonal mental pictures, extrapolated from our experience with projectiles and surf, for the propagation of energy and information. Hooke and Huygens argued for light as waves, citing thin-film interference and light's enormous speed. Newton argued for light as particles, pleading the lack of convincing diffraction.[5]

With the optical interference experiments of Thomas Young in 1800 and diffraction experiments of Augustin Fresnel over the two following decades, light was clearly shown to be a wave. The smallness of its wavelength explained why we do not casually observe optical diffraction in everyday life. The measurement of the speed of light in water by Foucalt in 1850 also ruled out the particle interpretation.

But what was waving? Maxwell's theory of electromagnetism, published in a series of papers in 1861-64, showed that waves in the electromagnetic field move at the speed of light. Maxwell's equations also predict optical phenomena such as Snell's law, the law of reflection, dispersion, and polarization. The question of what light IS seemed settled in favor of a *wave in the electromagnetic field.*

So in 1905 along comes this 26-year-old physicist, fresh out of graduate school and working in the Swiss patent office, one Albert Einstein, daring to resurrect the light-as-particle concept again. He acknowledged the obvious success of wave optics:

The wave theory of light, which operates with continuous spatial functions, has proved itself superbly in describing purely optical phenomena and will probably never be replaced by another theory.

But Einstein pointed out in the same paragraph a loophole in the "light as wave" doctrine:

One should keep in mind, however, that optical observations refer to time averages rather than instantaneous values; and it is

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Einstein's Quanta, Entropy, and the Photoelectric Effect

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quite conceivable, despite the complete confirmation of the theory of diffraction, reflection, refraction, dispersion, etc., by experiment, that the theory of light, operating with continuous spatial functions, leads to contradictions when applied to the phenomena of emission and transformation of light.

A wave model of light works fine in understanding pure electromagnetic radiation. In classical antenna theory a macroscopic continuous alternating current produces radiation fields that are, for all practical purposes, described by continuous functions. But when the "antenna" consists of a single molecule or lone electron, Planck's quantum might have the dominant influence. Einstein's argument was supported by the fact that situations already existed where the *interaction of light with matter* could *not* be completely understood in terms of light as a continuum. In a sweet irony of history, in 1887 Heinrich Hertz was testing Maxwell's theory by attempting to produce radio waves artificially in the laboratory. In this he affirmed Maxwell (and the development of radio technology by others soon followed). But in the course of his experiments that confirmed light to be wave-like, he also stumbled across an occurrence that would come to be called the "photoelectric effect," interpreted by Einstein in 1905, as a collision between electrons and particles of light! Hertz noticed that when certain metals were illuminated with ultraviolet light, some spurious electric currents appeared in his apparatus. He had the presence of mind to recognize this glitch as worth investigating. Several investigators besides Hertz studied the phenomena. Wilhelm Hallwachs, Julius Elster and Hans Geitel, Phillip Lenard, and J. J. Thompson assembled data on the photoelectric effect and its properties.

As students we were introduced to the quantum through Einstein's explanation of this photoelectric effect. But it was merely one *application* whereby he tested his broader concept of light quanta. He wrote,

Indeed, it seems to me that the observations of "blackbody radiation," photoluminescence, production of cathode rays by ultraviolet light, and other related phenomena associated with the emission or transformation of light appear more readily understood if one assumes that the energy of light is discontinuously distributed in space. According to the assumption considered here, in the propagation of a light ray emitted from a point source, the energy is not distributed continuously over ever-increasing volumes of space, but consists of a finite number of energy quanta localized at points of space that move without dividing, and can be absorbed or generated only as complete units.

In this paper I wish to present the train of thought and cite the facts that led me onto this path, in the hope that the approach to be presented will prove of use to some researchers in their investigations.

Einstein always began with fundamentals. Among the fundamental principles of physics are the First and Second Laws of Thermodynamics. When we first learned about photons we probably did not realize that Einstein's "train of thought" was pulled by entropy!

Entropy and Einstein's Quanta

Einstein's derivation contains two parts. In Section 3 of his paper he began,

The following treatment is contained in a well-known study by Mr. Wein and is presented here only for the sake of completeness.

In essence Einstein recalled the Planck distribution. In thermal equilibrium, the energy density of electromagnetic radiation in the frequency interval f to $f+\Delta f$ is given by[6]

$$U/V = (8\pi h\Delta f/c^3)\, f^3\, (e^{hf/kT} - 1)^{-1} . \qquad (1)$$

For brevity here let $A \equiv 8\pi h\Delta f/c^3$. If $hf >> kT$ then

$$U \approx VAf^3\, e^{-hf/kT} \qquad (2)$$

so that

$$1/T = -(k/hf)\ln(U/VAf^3) . \qquad (3)$$

Set this temporarily aside and recall the combined first and second laws of thermodynamics. A system's internal energy can be changed either by putting heat into the system or by the system doing work, so that for any reversible process

$$dU = TdS - PdV \qquad (4)$$

where S denotes the entropy of the system and P its pressure. For a constant volume process Eq. (4) says

$$1/T = dS/dU . \qquad (5)$$

Equating the two expressions for $1/T$ from Eqs. (3) and (5) shows that

$$-(k/hf)\ln(U/VAf^3) = dS/dU , \qquad (6)$$

which we integrate:

$$S = -(k/hf)\int \ln(U/VAf^3)\, dU . \qquad (7)$$

Using the integral $\int \ln x\, dx = x(\ln x - 1)$, we find

$$S = -(kU/hf)[\ln(U/VAf^3) - 1] + \text{const.} \qquad (8)$$

This was known before 1905. But at this point Einstein did something with it that was new:[7]

If we restrict ourselves to investigating the dependence of the entropy on the volume occupied by the radiation, and denote the entropy of radiation by S_o at volume V_o, we obtain

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$$\Delta S = S - S_o = (kU/hf)\ \ln(V_2/V_1) \ . \qquad (9)$$

This equation shows that the entropy of monochromatic radiation of sufficiently low density varies with the volume according to the same law as the entropy of an ideal gas...

To see what Einstein means, consider an ideal gas. With Einstein we consider the definition of entropy and the combined First and Second Laws of Thermodynamics,

$$\Delta S = \int dQ/T = \int (dU + PdV)/T \ . \qquad (10)$$

An ideal gas has the equations of state

$$PV = NkT \qquad (11)$$

and

$$U = Nk\, c_V\, T \qquad (12)$$

where N denotes the number of gas particles and c_V the heat capacity per molecule evaluated at constant volume. At constant temperature $dU = 0$ and $P = NkT/V$, so that

$$\Delta S = \int NkT\, dV/T = Nk\ \ln(V_2/V_1) \ . \qquad (13)$$

Now compare Eqs. (9) and (13): if we treat monochromatic electromagnetic radiation of frequency f as an *ideal gas of particles*, then upon equating these two expressions for entropy change we discover, for the total energy of this gas of *N particles of light* the expression,

$$U = Nhf \ . \qquad (14)$$

Because energy is additive, the energy E of a *single* particle of electromagnetic energy, corresponding to *waves* of frequency f is

$$E = hf \ . \qquad (15)$$

Einstein observed,[8]

From this we further conclude that monochromatic radiation of low density...behaves thermodynamically as if it consisted of mutually independent energy quanta of magnitude hf.

Where one may say there exists a harmonic electromagnetic wave of frequency f and wavelength λ, one may also say that there exists a swarm of free particles, the photons, each with energy $E = hf$.[9] One is tempted to ask, "Well, what is light *really*, particle or wave?" That is not the question. Einstein has shown us something important in the philosophy of science. Science is the art of *creating and testing concepts* in terms of which the physical world becomes comprehensible. "Particles" and "waves" are *models*, conceptual representations of light. Light is *like* waves in some situations, and *like* particles for different situations. David Bohm remarked,

We find a strong analogy here to the fable of the seven blind men who ran into an elephant. One man felt the trunk and said that "an elephant is like a rope," another felt the leg and said that "an elephant is obviously a tree," and so on. The question that we have to answer is: Can we find a single concept that will unify our different experiences with light, just as our concept of the elephant unifies the experiences of the seven blind men? [10]

Having created the concept of radiation quanta, Einstein turned to experimental tests. He discussed phenomena in photoluminescence, the ionization of gases by UV light, and "the generation of cathode rays by illumination of solid bodies" that we call the photoelectric effect.

Quanta and the Photoelectric Effect

This photoelectric effect occurs when you hook up a DC circuit but use light instead of a battery as the energy source. The heart of the apparatus is a "photocell," consisting of a good conductor such as potassium or cesium mounted inside a transparent evacuated tube. Conducting wires, one embedded in the metal, form a cathode and anode. Light shines on the metallic solid and liberates electrons, or "cathode rays," completing the circuit (see Fig. 1).

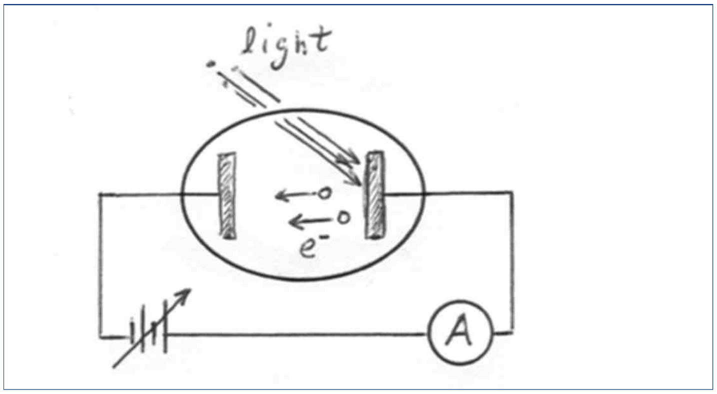

Fig. 1. Apparatus of the photoelectric effect.

In a world with continuous electromagnetic energy the emission of electrons would seem inevitable sooner or later. A bound electron would only have to soak up the light's energy until it saved enough to be set free. Alternatively, the electron might be a little resonator bound to its atom with restoring forces, like a mass held by a spring. A continuous light wave of frequency f would exert a harmonic driving force on the electron. A resonance could occur, and the electron's oscillation could grow so large that the "spring" breaks, liberating the electron. If that mechanism operates then one should see the electron currents occur only for a spectrum of overtones based on a fundamental frequency.

There's only one problem with these soaking and resonance mechanisms. The resonances do not occur, and the soaking model

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contradicts the facts. To illustrate the issues, let there be two knobs on our light source. With one we tune the light frequency f, with the other we control the light intensity I (average power per unit area). Since some electrons come from the surface while others come from deeper within the metal, we expect a range of electron kinetic energies. For a way to measure the maximum electron kinetic energy K_{max} we place in the circuit a battery whose polarity *opposes* the electron flow. One increases its opposing voltage from zero (requiring a third knob) until the most energetic electrons are stopped, making the current zero. By conservation of energy, K_{max} and the stopping voltage V_{stop} are related by

$$K_{max} = eV_{stop} \tag{16}$$

where e denotes the quantized unit of charge, $e = 1.6\times10^{-19}$ C.

Suppose we crank up the light source intensity very high. It shouldn't take long to liberate those electrons and produce a current! That indeed occurs, but *only* if the frequency lies above a threshold value! If we keep the intensity bright but decrease the frequency, we find a "threshold" frequency f_o characteristic of each metal. Once the incident radiation frequency drops *below* threshold, the electron current *abruptly* stops, no matter how bright the intensity! For a given metal sample, we can measure K_{max} as a function of frequency. We find a linear relationship, with the *same slope* for all metals:

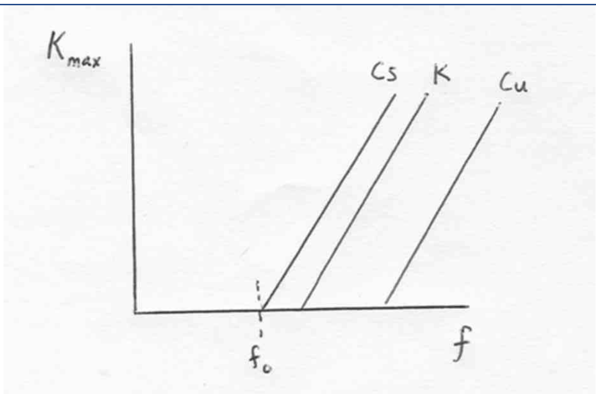

Fig. 2. Photoelectric phenomenology: maximum kinetic energy vs. frequency of the incident radiation.

When the frequency lies *above* threshold, photoelectrons are emitted astonishingly fast, even if the intensity is so low that it would take two weeks for the electrons to acquire enough energy via the "soaking" model! Furthermore, increasing the incident intensity at fixed frequency does not give *individual* electrons more energy; rather, it merely gives the same energy distribution to *more electrons.* This we know because the stopping voltage at fixed frequency is independent of intensity.

In terms of continuous waves, most features of the photoelectric effect make no sense. But the *sudden* emission of electrons under feeble light sounds like a *collision*! That's how Einstein interpreted the photoelectric effect: an electron was knocked from the metal in a collision between one particle of light and the electron. In Section 8, "On the Generation of Cathode Rays by Illumination of Solid Bodies" Einstein explains:

The usual view that the energy of light is continuously distributed over the space through which it travels faces especially great difficulties when one attempts to explain photoelectric phenomena, which are expounded in a pioneering work by Mr. Lenard.[11]

According to the view that the incident light consists of energy quanta of energy hf, the production of cathode rays can be conceived in the following way. The body's surface layer is penetrated by energy quanta whose energy is converted at least partially into kinetic energy of the electrons. The simplest conception is that a light quantum transfers its entire energy to a single electron...

Let the *least*-tightly bound electron be held to the metal with a binding energy of magnitude w (the "work function"); this electron emerges with *maximum* kinetic energy. Apply conservation of energy to the inelastic photon-electron collision. The energy of incoming photon equals the energy received by the electron. The electron spends the amount w of this energy in breaking free of the metal; anything left over sends it forth with kinetic energy K_{max}. Conservation of energy thus gives,

$$hf = w + K_{max}\ . \tag{17}$$

In terms of the directly observable stopping voltage, the value of kinetic energy can be written

$$eV_{stop} = hf - w \geqslant 0\ , \tag{18}$$

which means there can be no emitted electrons when f equals or drops below the threshold frequency $f_o = w/h$. The collision model thereby explains the threshold. In our notation for the stopping potential, Einstein said

If this formula derived is correct, then V_{stop} when plotted in Cartesian coordinates as a function of the frequency of the incident light, must give a straight line whose slope is independent of the nature of the substance under study.

As far as I can tell, this conception of the photoelectric effect does not contradict its properties as observed by Mr. Lenard. If each energy quantum of the incident light transmits its energy to the electrons, independently of all others, then the velocity distribution of the electrons, i.e.., the nature of cathode rays produced, will be independent of the intensity of the incident light; on the other hand, under otherwise identical circumstances, the number of electrons leaving the body will be proportional to the intensity of the incident light.[12]

The photoelectric effect data (available in Einstein's time, and repeated by every generation of physics students since), shows that a plot of eV_{stop} vs. f has a slope, within experimental error, equal to Planck's constant! That the same number h would emerge as just that

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needed to explain the Planck distribution *and* the photoelectric effect (and Einstein's other applications) could hardly be a fluke; *h*, the quantum of action was fundamental. From the moment of the publication of Einstein's paper, everyone had to take the quantum seriously (for this paper Einstein was recognized with the Nobel Prize in 1920). This paper is why we all study quantum mechanics today!

References

[1] Albert Einstein, "On a Heuristic Point of View Concerning the Production and Transformation of Light," *Annalen der Physik* **17** (1905), 132–148.

[2] For annotated translations of Einstein's 1905 papers see John Stachel, *Einstein's Miraculous Year: Five Papers That Changed the Face of Physics* (Princeton Univ. Press, 1998).

[3] Max Planck, "Ueber das Gesetz der Energieverteilung im Normalspectrum," *Annalen der Physik* **4** (1901), 553.

[4] Paragraphs in italics are Einstein's quotations from Stachel's translation in Ref. 2.

[5] For a tongue-in-cheek review of the history of "what is light," see "The Book of Lumen," *Radiations*, Fall 2001, pp. 7–10.

[6] In Einstein's paper he used β to denote what today we denote h/k, the ratio of Planck's and Boltzmann's constant.

[7] Einstein considers two different but fixed volumes that contain the same energy U of radiation having frequency f. How can the radiation have the same energy and frequency in different volumes? In terms of *waves* the radiation may have different amplitudes; in terms of *photons* the two volumes contain different numbers of particles.

[8] Einstein used ν for frequency, and said "independent energy quanta of magnitude $R\beta\nu/N$" (see note [6]). The ideal gas constant R is one mole of Boltzmann's constants, $R = N_A k$. I have modified Einstein's quotation by substituting modern notation for these constants.

[9] It's instructive to see where the photon concept leads when combined with Einstein's special theory of relativity. Because these particles *are* light, they move at the speed c. The energy and momentum of a free particle of mass m moving with velocity $\mathbf{v}$ are $E = mc^2\gamma$ and $\mathbf{p} = m\mathbf{v}\gamma$, respectively, where $\gamma \equiv (1-v^2/c^2)^{-1/2}$. Transpose the relation between mass and energy into $m = (E/c^2)(1-v^2/c^2)^{1/2}$. If $v = c$ then $m = 0$ regardless of E. Because $E^2 - (pc)^2 = (mc^2)^2$, for massless particles $E = pc$. For our single photon this becomes $hf = pc$, which by virtue of $c = f\lambda$ (where λ denotes the wavelength) gives $p = h/\lambda$. So much for massless particles. But this inspired Louis de Broglie in 1926 to postulate that, for *any* free particle, even massive particles, one could invoke wave-particle duality through $E = hf$ and $p = h/\lambda$, founding quantum mechanics as it's usually introduced.

[10] David Bohm, *Quantum Theory* (Prentice-Hall, 1951), p. 26.

[11] P. Lenard, *Annalen der Physik* **8** (1902), 169–170 (Einstein's reference to Lenard).

[12] P. Lenard, *Annalen der Physik* **8** (1902), 166–168 (Einstein's reference).

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beyond the course of therapy. Chris developed software tools to analyze successive hypoxia PET images of the same patient.

Leah Ezzell
(Mentor Dr. Ping Xia, University of California, San Francisco)

Leah had an opportunity to observe the clinical world of radiation oncology and to appreciate the important roles of medical physicists involved in cancer patient care. Leah worked on a research project to detect patient treatment positioning changes based on computed tomography (CT) image information.

Michael Fernald
(Mentor Dr. Thomas Bortfeld, Massachusetts General Hospital)

Michael worked with Alexei Trofimov, PhD on a project to use IMRT compensation of lung tumor motion. He learned how to minimize the effects of the motion via computer simulation then transferred the results to the linac. A moving phantom was irradiated and the radiation dose measured with film. He is currently preparing a technical note about his findings for publication in a scientific journal.

Stephanie Letchford
(Mentor Dr. Richard Wendt III, UT M.D. Anderson Cancer Center)

Stephanie experienced clinical medical physics and undertook a challenging research project in computerized image formation. Stephanie investigated SPECT scatter corrections and modified a research software package to suppress their effect. Her modified software was tested using simulated subjects. She also participated in the inspection of the structural radiation shielding in a new clinical building, acquired data for periodic quality control testing of imaging instruments, observed various clinical procedures and acquired data in the annual testing of a multislice CT scanner.

Sarah Witten
(Mentor Dr. Robert Jeraj, University of Wisconsin)

Sarah analyzed PET data acquired at different times during the course of a treatment to assess the effectiveness of radiation therapy. A special PET marker targeting cell proliferation was used and heterogeneity of cell proliferation during the treatment was confirmed. Her analysis indicated the need to adequately target the more proliferating parts of tumors.

The program committee thanks the mentors for their participation and encourages as many members as possible to offer their mentoring services. Each year mentor selection is primarily based on the needs of the selected fellow and often depends upon their home's geographical location. A large mentor pool distributed across the country is important to serve our fellows well.

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