Models of the structure of matter

Why should we care what students think?

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Abstract:

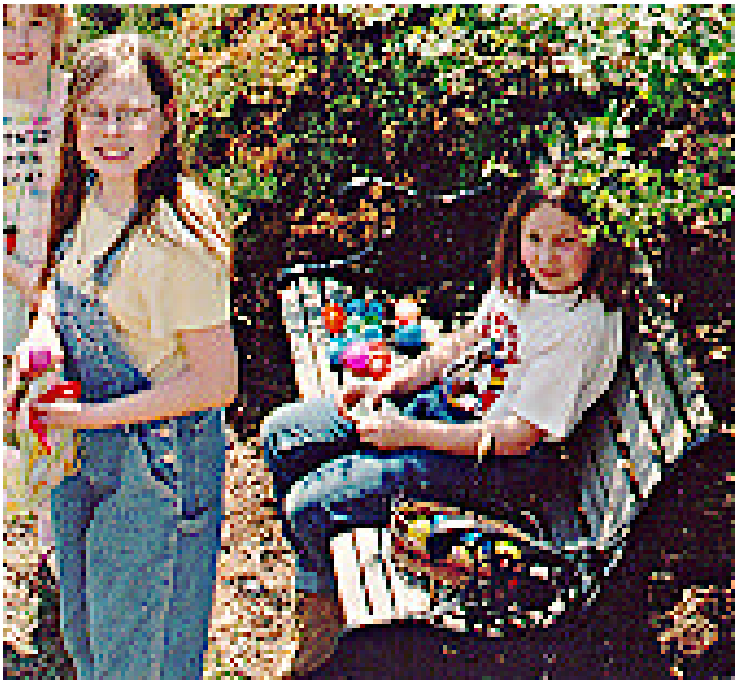
The OSU Physics Education Research Group has a great interest in student understanding of the structure of matter and the interaction of matter, with several efforts under way. My group has studied student understanding of aspects of quantization, the interaction of light and matter, and radioactivity.

Research supported in part by the National Science Foundation under grant DUE-9950528 and grants DUE-9653145, DUE-9751719, and GER-9552460.

MSaTERS, 5 May 2001

Why this picture is relevant

The future generations:



My kids —
and why this picture is relevant (millions of reasons, including millions of things)

wood
metal
plastic eggs
real eggs
cloth
dirt
etc. (remember this later)

Science vs. Myth

“The Independent Research Centre for Unexplained Phenomena was founded in 1993 by Paul Vigay, after a number of personal experiences and four years of extensive research into the continuing crop circle enigma. Paul was previously a UFO and paranormal investigator, but became interested in crop circles in 1989 when he discovered anomalous electrical effects in and around crop formations. After four years it became increasingly apparent that there was a real and genuine mystery to the subject. Not only have strange aerial anomalies (UFOs) been linked with crop formations, but many people and objects have been affected by their influence -- either positively or negatively. Another thing, which has become increasingly obvious during the last couple of years is the seemingly paranoid attempts by some skeptics and hoaxers to try to debunk the subject in the eyes of the general public.”

From the website http://www.cropcircleresearch.com/ quoted at CRANK.net.

Science vs. Myth

“Haber’s new model of the atom is that the nucleus is an oscillating skin, symbolically like that of a basketball. The incredibly quick oscillations of the skin create electrons that radiate outward and anti-electrons that radiate inward. He refers to the skin itself as the neutron shell. Done away with is the proton, which Haber claims has only created confusion in the world of Quantum Physics leading to a ‘particle zoo,’ the uncontrolled labeling of particles that don’t exist to create other particles that don’t exist, and such concepts as renormalization, in which both sides of a mathematical formula are divided by zero; unthinkable even to 9th grade algebra students. Haber describes the fleeting particles that are created in bubble chambers and particle accelerators as being fluke events and not actual particles.”

From the website http://www.haberco.com/ns/ns5.html found at CRANK.net.

Science vs. Myth

“An effect based on magnetic fields that generates a continual motion of magnetized rollers around magnetized rings producing electric energy and, under certain conditions, an anti-gravity effect that can be used for propulsion. Side-effects include negative ionization of surrounding air and a cooling of temperature around the device when in operation. ... Prof. John Searl is the ONLY man in history to have built and flown an antigravity device called a levity disc, now called Inverse-G-Vehicle.”

From the website http://www.searleffect.com/ found at CRANK.net.

Science vs. Myth

“For years, there have been rumors, almost in the urban legend category, that the Soviet Union had developed some mysterious substance called ‘red mercury’ that can be used in nuclear weapons construction, and that this ‘red mercury’ may be available on the black market for 1000- 2000 per kilo. Rumors have touted it as being able to just about anything including: making stealth aircraft stealthier, infrared sensors more sensitive, counterfeits harder to detect, and fission and fusion bombs smaller and easier to construct. It may be radioactive or not. It may be the densest material or it may not. ... I would wager that red mercury may be useful for much more than destruction. What can kill can cure, eh? Anyway, the truth makes free.

HOW TO TURN QUICKSILVER INTO A WATER WITHOUT MIXING ANYTHING WITH IT “

From the website http://www.stormloader.com/joshua/redmercury.html found at CRANK.net.

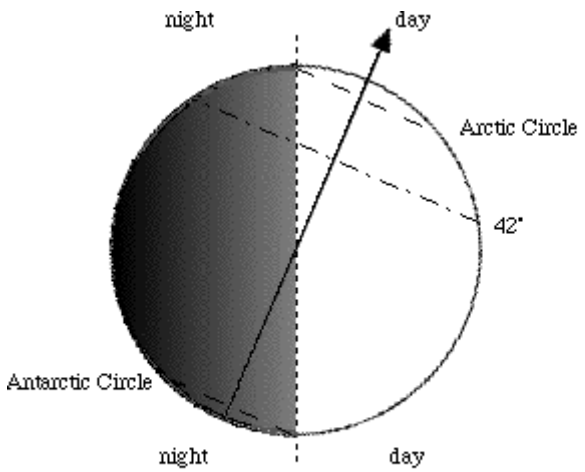
Science vs. Myth

You've heard them:

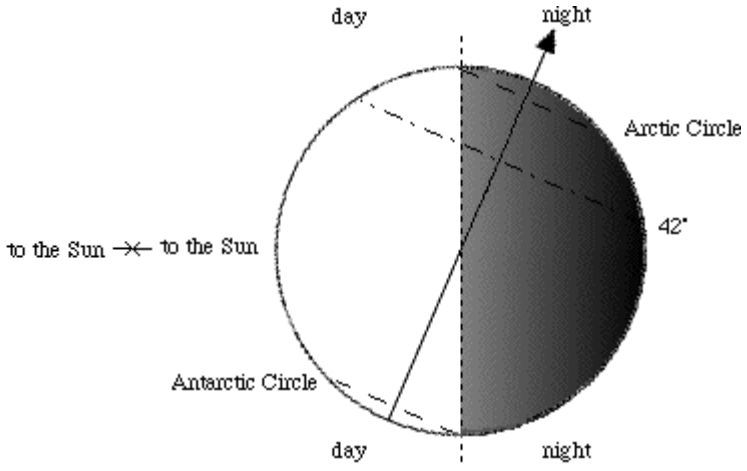
"The reactor'll melt its way down through the ground to China ..."

"Don't stand too close to the microwave or the radioactivity will get you ..."

"Its warmer in summer because Earth is closer to the Sun ..."



Northern Hemisphere Summer



Northern Hemisphere Winter

Science vs. Myth

Recurring Science Misconceptions In K-6 Textbooks by William J. Beaty

A selection of THE MISCONCEPTIONS listed:

THE GRAVITATIONAL FORCE IN SPACE IS ZERO
SALT WATER IS FULL OF SODIUM CHLORIDE MOLECULES
THE NORTH MAGNETIC POLE OF EARTH IS IN THE NORTH
A WING'S LIFTING FORCE IS CAUSED BY ITS SHAPE
BEN FRANKLIN'S KITE WAS STRUCK BY LIGHTNING
ONE PRISM SPLITS LIGHT INTO COLORS; A SECOND IDENTICAL PRISM RECOMBINES THEM
LIGHT AND RADIO WAVES ALWAYS TRAVEL AT "THE SPEED OF LIGHT" —300,000 km/s
RAINDROPS HAVE POINTS AT THEIR UPPER ENDS
AIR IS ALMOST ENTIRELY WEIGHTLESS
SHADOWS VANISH ON CLOUDY DAYS BECAUSE THE SUN ISN'T BRIGHT ENOUGH
INFRARED LIGHT IS A FORM OF HEAT
THERE ARE SEVEN COLORS IN THE RAINBOW
EARTH'S NORTH AND SOUTH MAGNETIC POLES RESIDE JUST BELOW THE SURFACE
CARS AND AIRPLANES ARE SLOWED DOWN BY AIR FRICTION
IRON AND STEEL ARE THE ONLY STRONGLY MAGNETIC MATERIALS

Science vs. Myth

Associated Press article "**Study Finds Errors in Science Textbooks**," 15 January 2001

"Twelve of the most popular science textbooks used at middle schools nationwide are riddled with errors, a new study has found.

"Researchers compiled 500 pages of errors, ranging from maps depicting the equator passing through the southern United States to a photo of singer Linda Ronstadt labeled as a silicon crystal."

TIMSS

Performance of American students on the Third International Science Study (TIMMS) was:

above the world average at the fourth grade level,

just below the world average at the middle school level,

and

significantly below the world average at the high school level.

The TIMMS report on high school seniors' performance in physics states, "[The] average performance in Norway was comparable to or even exceeded performance at the 75th percentile in ... countries such as ... the United States" In fact, U.S. students' 95th percentile lies at about the Norwegian students' 25th percentile!

A club has 86 members, and there are 14 more girls than boys. How many boys and how many girls are members of the club?

Twenty-nine percent of US eighth-graders answered this question correctly; 72 percent in Singapore; 66 percent in Taipei, Taiwan; 40 percent in Russia.

Can your eighth-grader do this?

A club has 86 members, and there are 14 more girls than boys. How many boys and how many girls are members of the club?

Show your work.
(answer given in the text)

$x + (14 + x) = 86$
$2x + 14 = 86$
$2x + 14 - 14 = 86 - 14$

$\frac{2x}{2} = \frac{72}{2}$

$x = 36$

$86 - 36 = 50$

Answer: There are 36 boys and 50 girls.

Diana Jean Schemo, "**U.S. Students Fail to Keep Up in Global Science and Math Tests**," *The New York Times*, December 6, 2000.

" If we're going to look at international math and science scores, we've got to look at the extent to which all children in America have access to qualified teachers in these areas," says Chuck Williams, director for teacher quality at the National Education Association. "Youngsters in urban communities have less chance to have a teacher who is licensed in math and science than in any other area," he adds.

US eighth-grade students are less likely than their international peers to be taught math by teachers who majored in the subject (41% versus 71%).

There are also considerable differences in teaching style and curriculum. For example, US classrooms attempt to cover many more subjects in a year than high-performing classrooms in other countries. And eighth-grade students spend less time than their international peers studying mathematics or science outside of school.

"Some US teachers have the idea that most kids can't learn algebra; even parents believe it. But that's not true in other countries," says James Stigler, professor of psychology at the University of California, Los Angeles. "You end up holding yourself to a lower standard than is necessary, and ultimately that's not good for the nation."

Our research:

My group at Ohio State University is working on how students understand

quantization and the interaction of light and matter

and

radiation and radioactivity.

Your part in this:

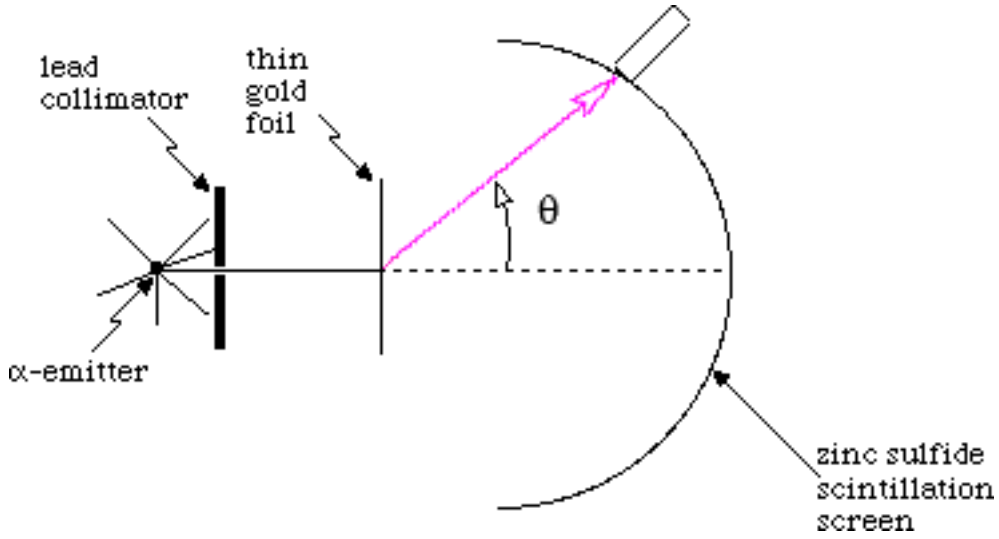
We are distributing three pieces of paper with pictures on them. They contain ranking tasks connected to these topics. Please take a few minutes to rank the items, and return them.

Atoms
Radioactivity
Radiation

The universe is made up of small particles that are gathered into larger assemblies.

How do we know?

The Geiger-Marsden Rutherford scattering experiment. The zinc sulfide is fluorescent and glows when hit by a particle. The microscope is moved around the screen to cover the sphere about the target and allow the number of scintillations in a given time to be counted by the experimenters. They expected all counts for $\theta \sim 0$, but found that **counts occurred for θ near π** (180°).



"It was quite the most incredible event that ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

Ernest Rutherford, 1909

So, after Rutherford's lab continued with its work for another two decades, physicists came to a model of the atom as made of just three constituents.

They are

protons,

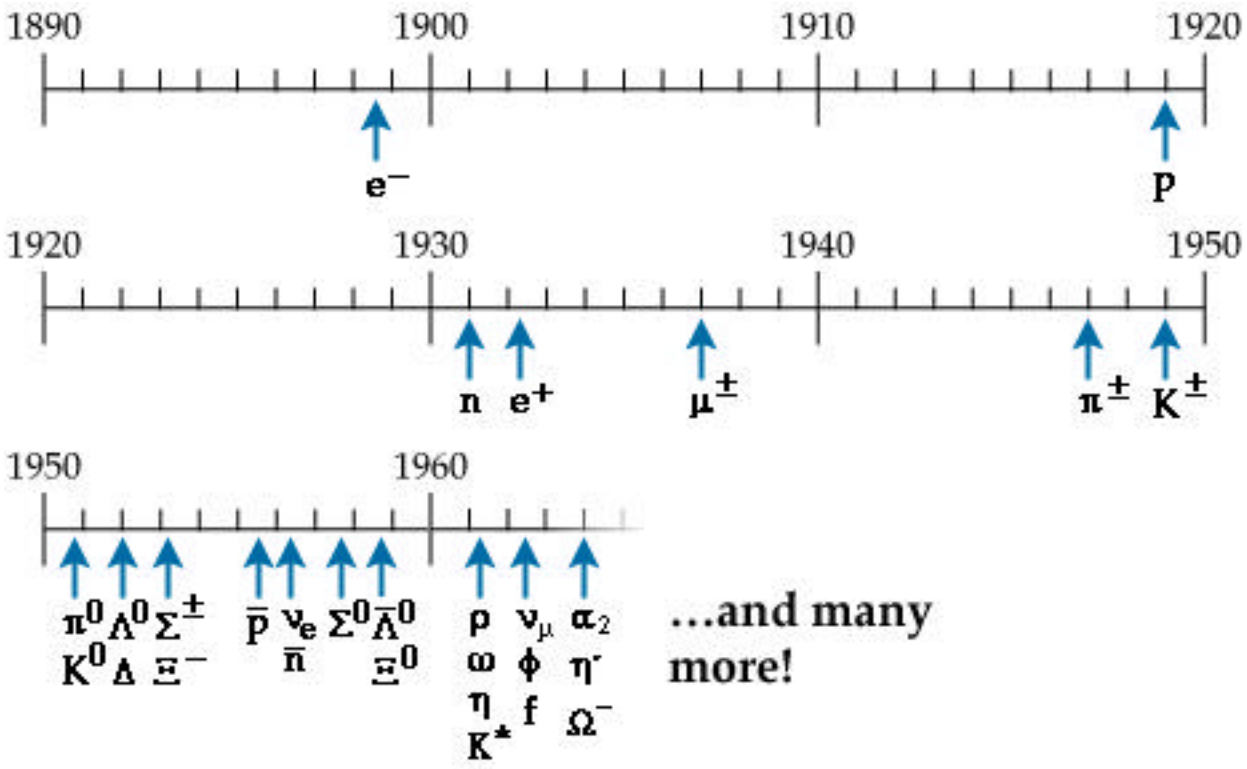
neutrons,

electrons.

Those millions of things are just three!?

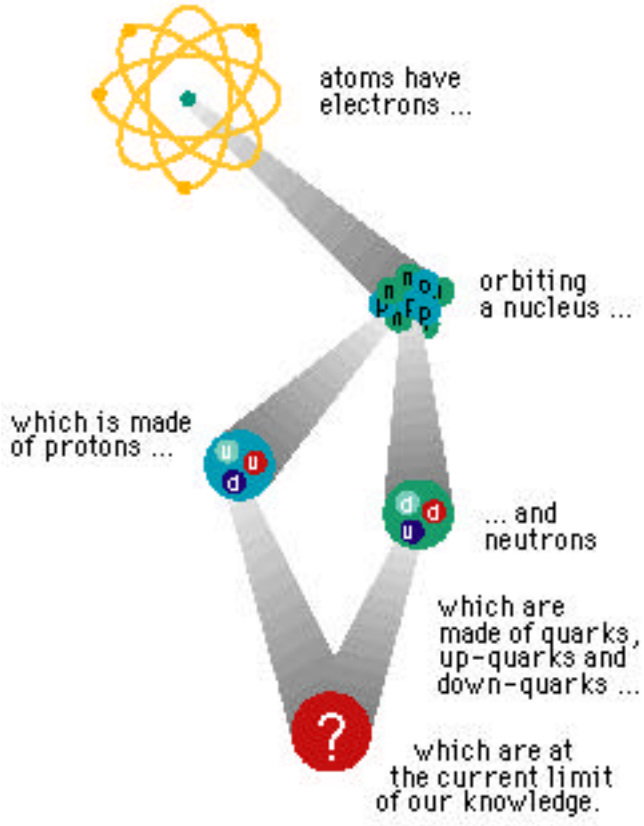
... experimental physics marches on!

The Particle Zoo



See our CPEP materials!

How do we see inside?



See our CPEP materials!

cpep@cpepweb.org

Our group's intention throughout has been to let the students themselves lead us into an understanding of their own ideas about quantization and the interaction of light and matter through interviews and surveys based on the interviews. We think we know things, but we have little conception of how our students view these matters. To be able to teach them, we need to be able to reach them where they are.

Why be interested?

1. **We've taught students these topics for many years, and don't really know what the students as a group are thinking, either before or after we have taught them. We'd like to know more so we can be better teachers.**

2. **Most people fear what they do not know, and make their lack of knowledge into a shield. Then they can be led by media misunderstandings. Remove the mystery, remove the fear.**

3. **Quantization is connected to all these ideas, and one can say without exaggeration that quantization *is* the physics of the twentieth century.**

Quotes from:

Physics in a New Era
An Overview

NATIONAL RESEARCH COUNCIL, 2001

“An atom or molecule in such a light field is really no longer an atom or a collection of atoms, but rather a new regime of matter, with the electrons, atomic nuclei, and light field having equal roles in determining the structure and behavior.”

“Many structures in nature are well organized on the nanoscale. For example, a seashell has a complex interleaved structure with exceptional strength yet low mass. ... So-called diblock copolymers are a beautiful example from chemistry: polymer blends that give perfectly organized and highly controlled structures on the nanoscale.”

Quotes from:

Physics in a New Era
An Overview

NATIONAL RESEARCH COUNCIL, 2001

“The study of nanoscale electronic devices began to blossom in the last decade and a half. It is now possible to fabricate devices that are so tiny that the charging energy needed to add or remove a single electron becomes easily observable. In some cases even the spacing of individual electron energy levels is large enough to be discernable, making these devices analogous to artificial atoms.”

“We are in the midst of an exciting revolution in the ability to observe and manipulate material at the quantum level. The next few decades are certain to lead to new insights into the strange world of quantum physics and to dramatic advances in technology, as the field of quantum engineering is developed.”

Some definitions:

Atom: Entity having a central nucleus containing protons and neutrons forced together by the strong interaction. Electrons are also in the atom. They do not really "move" as classical particles, but are represented by wavefunctions that give the probability amplitude for the electron at all points in space.

Radioactivity: the transformation of a nucleus into a different nucleus and simultaneous emission of energetic particles.

Radiation: that which is radiated, emerging along radii (spokes).

One problem with interviews is that the students have to speak and are unused to doing so as they think.

What to do?

Use ranking tasks!

David Torick, a graduate student from education working with me on the radioactivity project had seen the ranking task book by Heiggelke, Maloney, and O'Kuma,[1] and was inspired to try this.

I was skeptical that it would be useful, but we tried it and found that having the task to talk about made students much more garrulous. We have been using these ranking tasks since.

1. T. O'Kuma, D. Maloney, and C. Hieggelke, *Ranking Task Exercises in Physics* (Upper Saddle River, NJ: Prentice Hall, 2000).

Ordering of the pictures of models of the atom, according to a physicist.

J. This reflects the probability interpretation and shows where the electrons most probably are.

I. Again, the idea of probability is there.

H. At least there's a nucleus. A classic (?) textbook illustration.

C. At least there's a nucleus, but why should the electrons move in a "planetary" plane?

K. At least there's a nucleus. A classic (?) textbook illustration in chemistry texts.

A, D. The Thomson "plum pudding" model that led Rutherford's group to do their experiment.

F. Why rings?

E. Why relatively continuous density gradient?

B. The original model of Democritus. Not too useful.

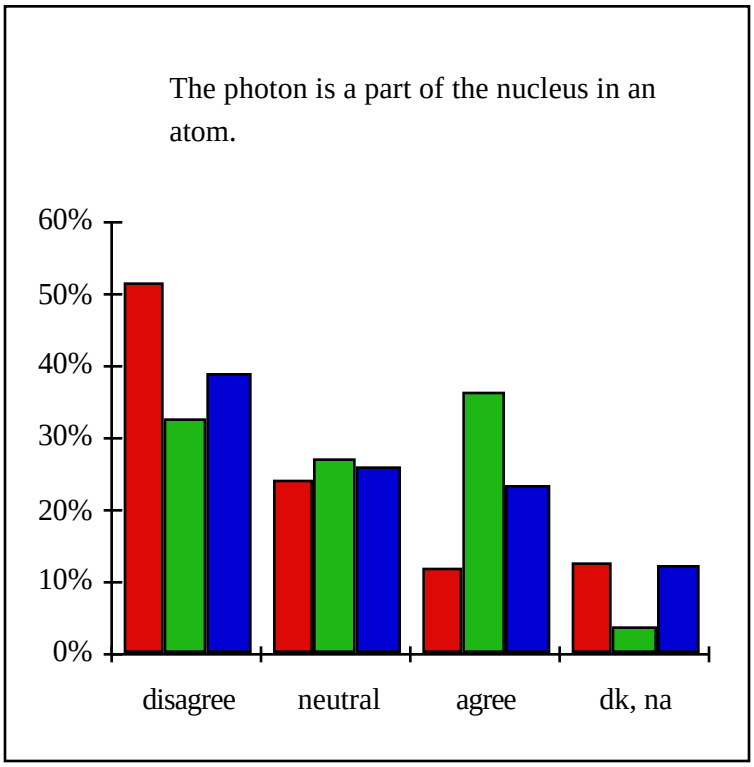
G. Ridiculous.

Among the ideas we have found in the interviews are:

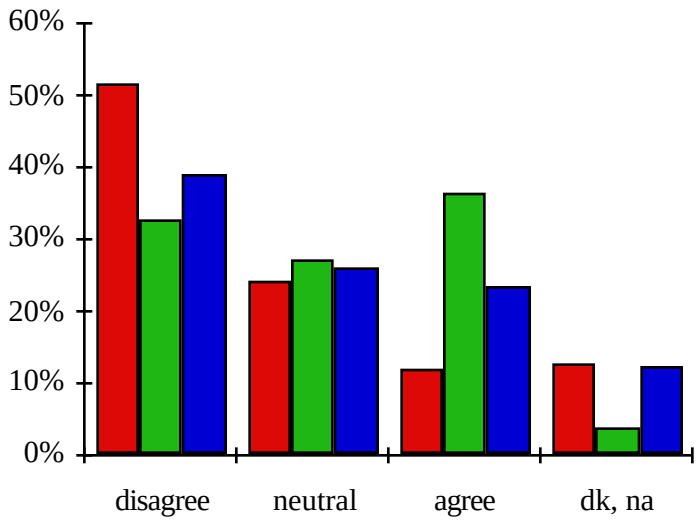
- Photons are not light.
- A particle cannot be a wave.
- A wave cannot be a particle.
- Light is not a particle.
- A photon has no size.
- A photon's size is related to its wavelength.
- Waves that go through slits are trimmed if their amplitude is too large.
- Waves that go through slits are trimmed if their wavelength is too large.
- Waves that go through slits bend at a sharp angle and then continue in a straight line.
- Photons are made up of smaller particles.
- Protons are made up of smaller particles.
- Energy levels correspond to electron positions in atoms.
- Valence electrons in atoms carry photons.

We then tested the ideas we found in interviews. The students who took our multiple choice, multiple response and Likert item survey fell into three categories:

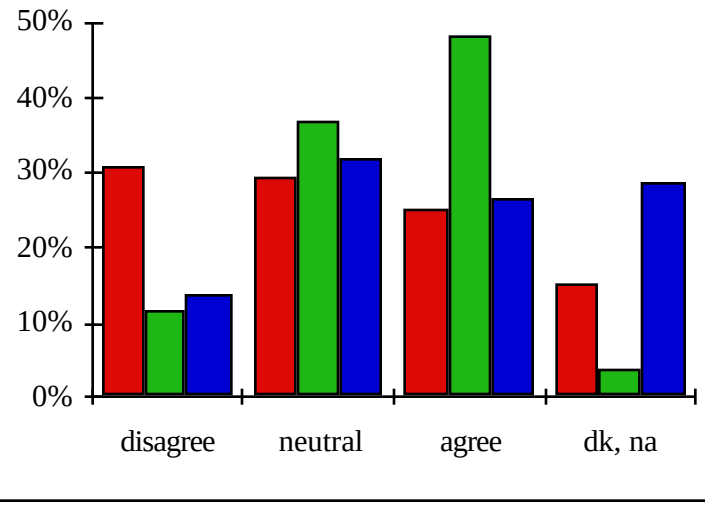
engineers
technical students
non-science, non-engineering



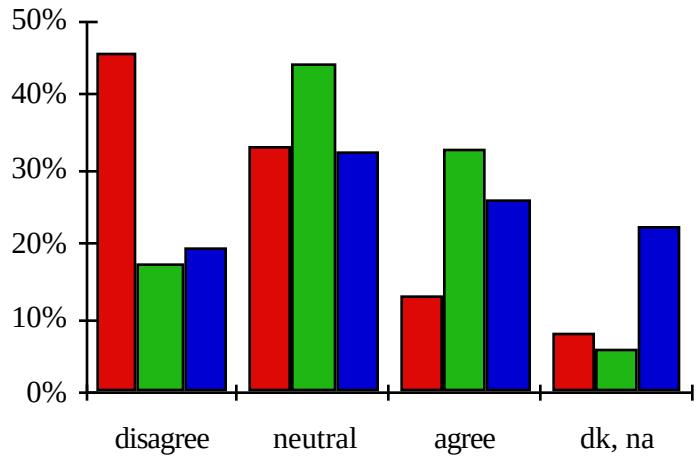
The photon is a part of the nucleus in an atom.



There are particles of light inside the photon that move at the speed of light



Photons are composed of several spherical parts, like atoms are.



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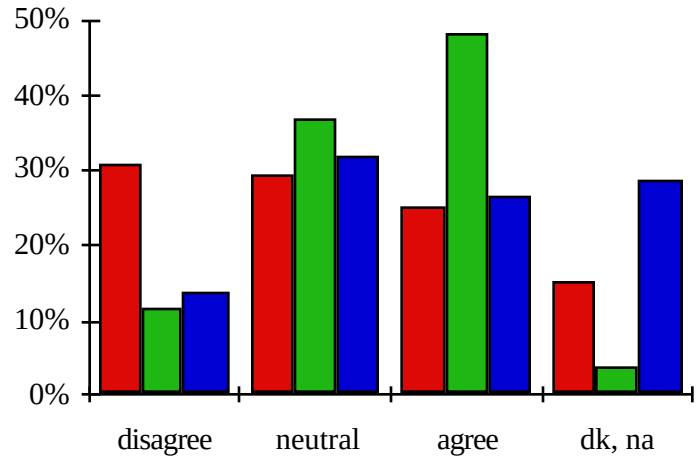


Dan believes atoms gain energy from both accepting and emitting a photon.

I: Okay. The blue doesn't quite ... The violet line produced by the mercury isn't quite in the band of the blue filter, it's probably on the edges or something. So, do you think that atoms can take and interact with light?

Dan: The electron stores photons.

I: Okay, so the electron stores photons.

Dan: Yeah. Somehow. I, I don't know what I want to say. (laughs)

I: Go ahead.

Dan: *I want to say in a spark, you'd see a light.*

I: Right.

Dan: If you see something sparking, that's electrons traveling. I want to say they give off a photon at that point. You'd see that light.

I: Okay.

Dan: I don't know if that's right.

I: Okay. So, after this electron gives off this photon, does the electron have more or less energy? Or does energy stay the same?

Dan: I'm gonna say the energy stays the same.

I: Why?

Dan: I think the electron's just a carrier. I don't know. I'm not gonna say.

Abe has described “good physics,” but probing reveals that he thinks that bonds weaken as photons are emitted or absorbed (much as a metal weakens if it is repeatedly bent). Abe further believes that white light is “just how light comes.”

I: [Do] you think an atom changes when it gives off light?

Abe: Yeah. Like I said, I think it tries to get back to its original state. When electrons are added to it, it tries to go back to the state it was before. But, you know, it keeps throwing off the energy as light. I think eventually, it would weaken whatever bond it had to the other atoms.

I: Why do you think that?

Abe: Because you know, it’s energy and electrons are being added to it and being taken away, in this process of back and forth, and I think it weakens it to the point where it’s not going to bond to another atom.

What about the radioactivity? A physicist's classification.

High

Age of dinosaurs (E), Far from civilization (G)

Why?

Rock (granite) has substantial thorium and uranium concentrations, and these are α emitters.

May be high

Kitchen (D; microwave irrelevant), Hospital operating room (F), X-ray lab (H)

Why?

Radon is radioactive. It concentates in closed rooms unless active steps are taken (in some regions of the country).

Low

Nuclear aircraft carrier (A), Nuclear power plant (C), Auto assembly plant (B), High-tension wires (I)

Why?

(A, C) Outside the shielded reactor cores, there is very low radioactivity.
(B) Large building, mostly outside air, little radon
(I) Outside air, little radon

What about the radiation? A physicist's classification.

High

Hospital operating room (F), X-ray lab (H)

Why?

When the x-ray machine is on or barium is used or radioactive pellets are inserted, there is exposure to the products of radioactive decay and to the x radiation.

Low

Nuclear aircraft carrier (A), Nuclear power plant (C), Auto assembly plant (B), High-tension wires (I), Age of dinosaurs (E), Far from civilization (G), Kitchen (D)

Why?

All have exposure to cosmic rays, all are equally exposed. (The microwave radiation is nonionizing!)

Student comments:

Aircraft carrier:

I do not know that much about some of the things, but the nuclear power plant, and the nuclear aircraft carrier, would to me, be great sources of radioactivity.

Assembly plant:

The car assembly plant, because, again, just seeing all those electrical waves. And I think that equates to radioactivity, too.

There is machinery there, so that just make so that just makes me think that that could be more radioactive than being away from civilization or age of the dinosaurs.

Nuclear power station:

The nuclear power plant I think will be next, because again, the way I think there is just a lot not known about the nuclear, and I guess I just do not understand when I hear it on the news, about the nuclear power plant and how it can affect you. … So I think that there is more to it than what we can see, and nuclear just sounds like a terrifying word to me.

High tension wires:

Well, the first thought that comes to my mind is, supposedly those people who live near high-tension electrical wire, that they are receiving doses of radiation.

I don’t think you would be able to build houses right next to them or whatever if they did. I think there would be more of a concern if they had a lot.

Age of dinosaurs:

I am going to say E is the least, without thinking much. Because, as far as I understand, most of the radioactivity around today is because we have generated it in our technology.

E the least, because there was not man on the planet making extra, generating, making nuclear power plants and stuff.

Well, I probably would go with the past day as the least amount of radioactivity. Just because, well, I don't think there is any electricity around back then … [Next] I would go with miles from civilization, 'cause when I think of radioactivity, I think that of electronics and power lines and appliances and that kind of thing.

Because I was thinking that like plutonium and uranium, I think that they occur naturally in nature, they can be found there. And I just think that now we are probably were those things are because we use them for different things, like the nuclear power plant, so I think that there would be less in the Earth.

I think the least would be right here, at the age of the dinosaurs. Because I just think a lot of that area was just more natural it was not touched by humans.

I think that after this time period when the dinosaurs lived in, humans began to contaminate the land a little bit more. And so when I see this human being ... something just triggers in my mind, like someone messed with this environment.

The age of the dinosaurs would be closer to the birth of the Earth ... But anything that did have half-lives that have gone through their half-lives have already started to deteriorate by this point, the miles from civilization. Whereas here, not as many things would have deteriorated.

Hospital operating room:

I would say hospital operating room, next because I feel like, I always see the warning signs, like warning radiation. Like maybe there is stuff that is used that has radiation in it.

I don't think they have, I mean, I am not really sure how they work, is it radiation that is even an issue with them. And if it is, it is that not different than radioactivity.

Far from civilization:

I would say that G, miles from civilization, may have some but I don't think it is going to be very strong. 'Cause I am not sure, but I think uranium occurs naturally, and maybe there is some just given off naturally from the Earth.

I know that there is natural radioactivity occurring, like in certain, probably, rocks and minerals and things. And those things are going to be present now and when the dinosaurs are around, too.

Just because there is not a lot of stuff that man generates, same theory as the dinosaur thing.

X-ray lab:

I am thinking this x-ray lab, because really what I heard more so when I go to a doctor and get a checkup. Or I have had x rays before and they always put, this something over you to cover vital organs or whatever. And so I just think that that is the most.

You always have to wear lead gear when you are getting an x ray, I would guess H first. ... No lead things no nothing, I would think that this is probably the greatest, the x ray.

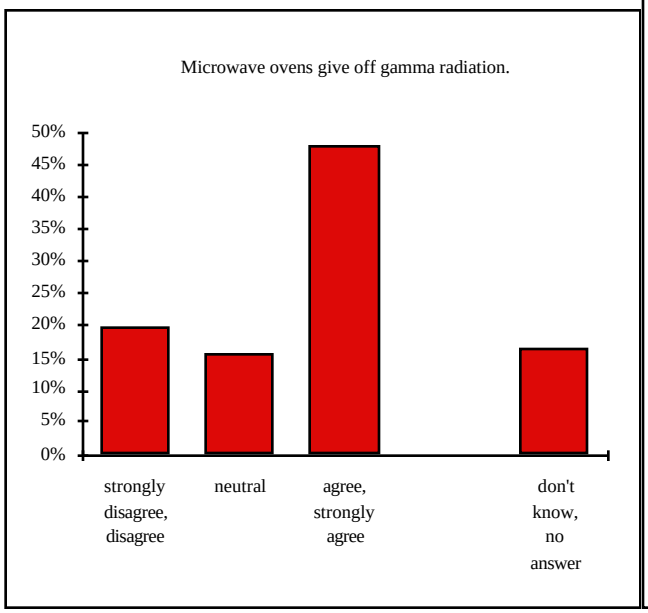
Microwave oven:

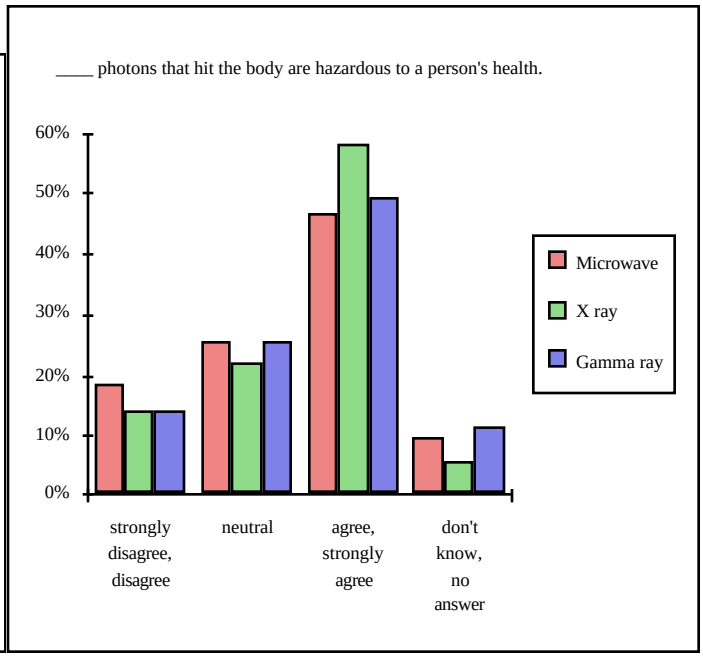
Um. Well, I assume some radiation is being emitted from the microwave oven, which is why you're not supposed to stand in front of it.

The microwave oven does stuff that I cannot even begin to guess at. If you were to stick a cat in the microwave, you better not be expecting it to come back out alive.

Could be things wrong with my kids.

[T]he microwave, I think ,will be next, because again it's, like, the radioactivity to warm up food and stuff like that [sic]. And to be honest with you, I don't know if some of those waves are going into that food when I warm it up. And I just think that anything manmade can have a negative effect to humans. That we can not see right up front, but maybe 10 to 15 years down the line may develop into cancer or birth defects.





Student ideas about radioactivity were pretty unscientific and conventionally muddled.

•many students unable to recognize environments representing the radioactivity

•perceived danger from radiation depends on the “more is more” idea that the greater the number of radioactive atoms present, the greater the health hazard

•students often do not recognize which information they need to answer questions

•many students misuse information on mass, mean life, half-life, and decay rate

•human artifice and technology are seen as the sole sources of radioactivity and contamination

•the greater the number of radioactive atoms present, the greater the health hazard (regardless of the activity, i.e., independent of the decay rate)

Characteristics of Module 1, detection

- introduces Geiger-Müller counter
- radioactive balloon experiment
- ionizing radiation
- background radiation
- count rate
- uncertainty

We use our research to ask students questions that explore their preconceptions. An example:

Two other students are having a discussion. Explain whether you agree with student 1, student 2, both students, or neither one.

Student 1: *Our background is 0.20 counts per second. The object we measured with the Geiger counter registers 105 counts per second. The object is a source of ionizing radiation.*

Student 2: *You can't say that. The greater the count rate, the faster the object decays. It's decaying away so fast it can not be a source of ionizing radiation.*

Characteristics of Module 2, measurement

- Sources of radiation—which ones are so?
- How decide if something is radioactive?
- Are irradiated objects radioactive?
- The difference between contamination and irradiation

We use our research to ask students questions that explore their preconceptions. An example:

Consider the following debate between two students regarding the fruit on the radioactive plate:

Student 1: *We saw that the fruit was absorbing the radiation from the object. I think radiation trapped inside the fruit will cause the fruit to become radioactive.*

Student 2: *I disagree. I don't think that the radiation given off is radioactive. I think the object that produces the radiation is radioactive. Some of the radioactive object would have to get onto or inside of the fruit to cause the fruit to become radioactive.*

Do you agree or disagree with the students' comments. Explain your reasoning.

Characteristics of Module 3, decay

- Using dice to simulate radioactive decay—an unconventional twist

We make sure they know that the decayed "nuclei" are not lost.

- What N(t) and activity are, how they are connected.

- Decay curves

- Meaning of "exponential."

- Relation of lifetime and decay rate.

- Half-life.

Characteristics of Module 3

We use our research to ask students questions that explore their preconceptions. An example:

Consider the following colloquy among three students regarding the effect of the half-life of a sample of a radioactive material, carbon-14. Assume that the half-life of carbon-14 is 5700 years.

Student 1: *After a thousand decays, half of your little pile of carbon-14 there is going to be gone. There is still going to be a thousand decays coming from the half the substance that's left.*

Student 2: *For carbon-14, 5700 years is the half-life. In order to insure it will be all gone, I would say you would have to have it for a time double the half-life. Because if only half the nuclei decay in that amount of time, who is to say that one atom you have is in the half that is going to decay or not decay?*

Student 3: *I picture the carbon-14 as a glowy thing. I have the glowy thing, which is just the intensity of the radiation is decreasing, and then I have the half-life, which tells me half of the material disappears after a given unit of time.*

Discuss whether you agree or disagree with the students.

Explain your reasoning.

Characteristics of Module 4, shielding

- Absorbers.
- Behavior of α, β, and γ compared.
- Effect of increasing absorber thickness.

We use our research to ask students questions that explore their preconceptions. An example:

Two students are arguing about detection of radiation as the source is moved relative to the detector. Explain which student you agree with and why.

Student 1: *When the source is moved farther away, there is a beam coming toward the Geiger counter and the count rate remains the same, no matter how far away the source is moved.*

Student 2: *The count rate decreases when the source is moved farther away from the Geiger counter. Since the particles are emitted in all directions, fewer of them hit the window of the Geiger counter.*

It is worthwhile for citizens to know what and why we believe there are tiny particles making up everything in the world. The process of science, the way science uncovers this understanding could help lead to lesser fear of the unknown and less mythmaking.

We are finding out about initial states of students. The discrepancies between student "initial states" and expert thinking will, we hope, give us clues as to how to help students change their organizational principles.

Radioactivity draft modules are available in pdf format at URL

http://www.physics.ohio-state.edu/~physedu/projects/details/radioactivity.htm

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