Introductory Students' ideas about Quantization and the Photon

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Abstract:

Because quantization is fundamental to twentieth century physics, it is important to explore student ideas about it. We discuss our assumptions and indications from interviews with students at various educational levels and faculty. Introductory students in Physics by Inquiry courses have similar ideas about quantization as students in the introductory engineering courses. We discuss the answers of students to draft questionnaires on these topics.

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The survey

We gave three versions of a survey to various groups of students—we will characterize them as

engineers
technical students
non-science, non-engineering

The engineers and non-science, non-engineering (we'll abbreviate this as ns—ne below) were students at Ohio State University, specifically students taking the second quarter of the engineering sequence and students in Physics by Inquiry courses (electric circuits) and "World of Energy" courses. The technical students attended the Ohio Mechanical Institute of the University of Cincinnati (many thanks to Prof. James Sullivan for his help).

Tom Kassebaum will describe details of the survey in the following talk.

Here, we will concentrate on what students said.

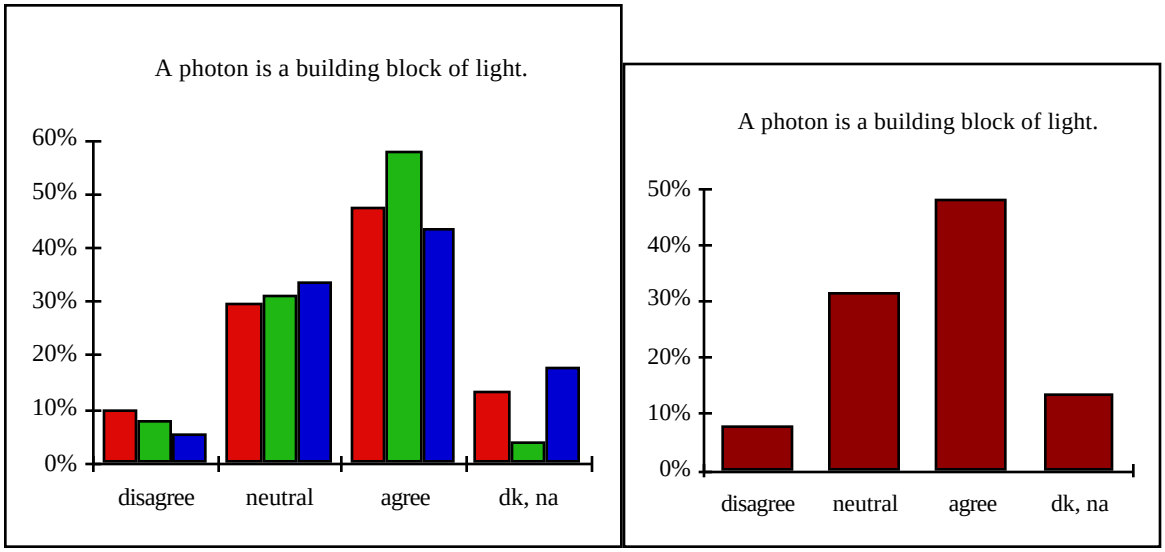
All students surveyed appeared to know some things about photons but little about quantization.

We used a five-item Likert scale plus “don’t know,” which is summarized as general agreement or disagreement.

For the item

A photon is a building block of light.

the differences among groups—engineers, technical students, ns—ne—is insignificant, so we use the summary.

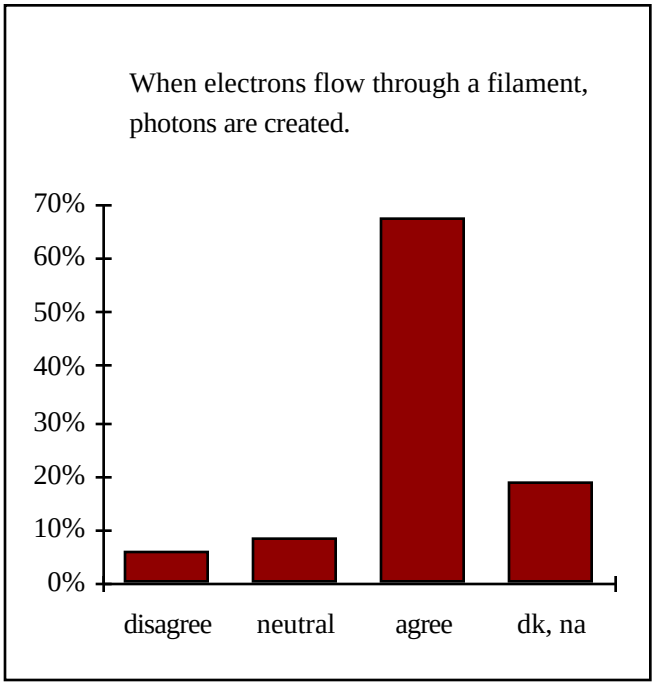


“Agree” means strongly agree or agree. “Disagree” means disagree or strongly disagree. “dk, na” means don’t know, no answer.

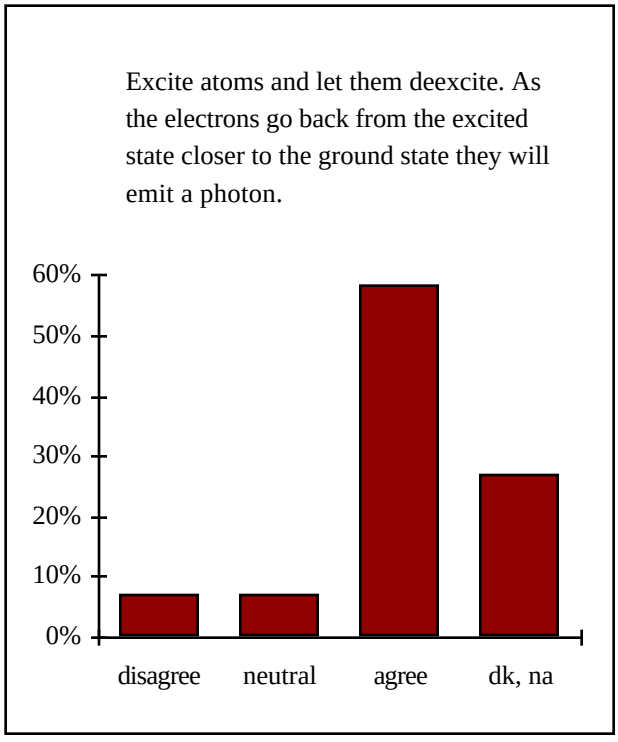
			N	disagree strongly disagree	agree strongly agree	**asa-dsd** **-13%**
41 BC	A photon is a building block of light.	engineers	112	10%	47%	**38%**
		tech students	52	8%	58%	**50%**
		ns—ne	108	6%	44%	**38%**
		total	272	8%	48%	**40%**

Again we see that students do know some things before these topics are treated in physics classes.

When electrons flow through a filament, photons are created.

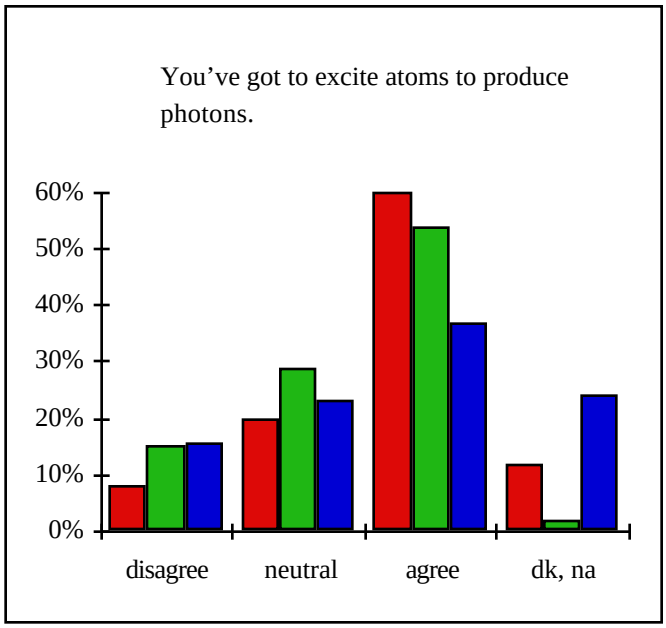


Excite atoms and let them deexcite. As the electrons go back from the excited state closer to the ground state, they will emit a photon.

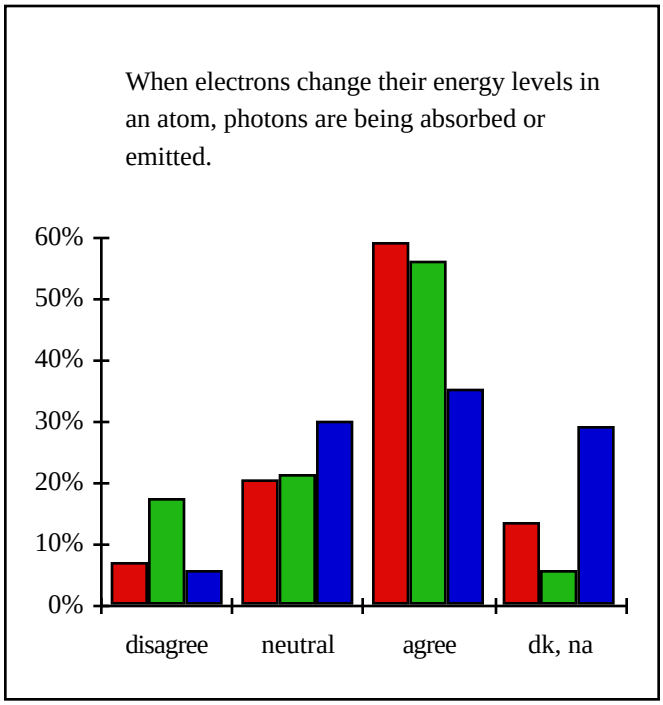


Engineering students seem to have an edge over other students in their original knowledge state.

You've got to excite atoms to produce photons.

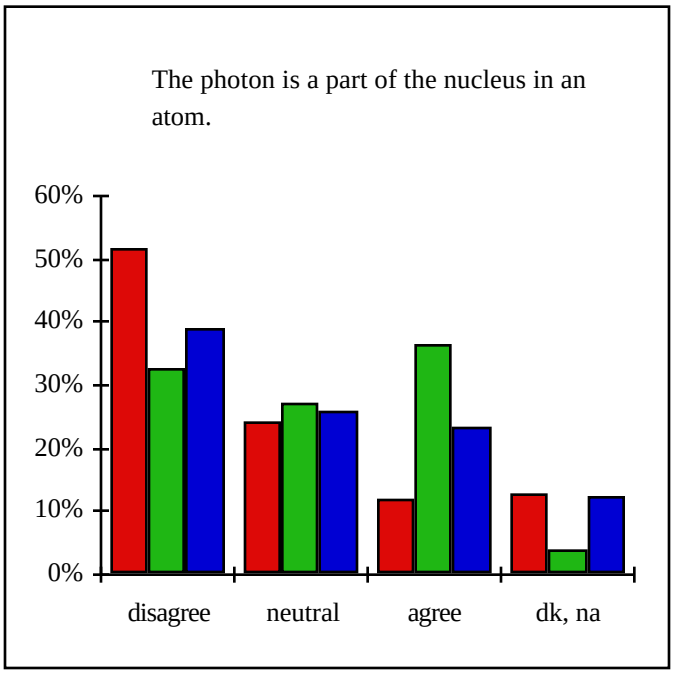


When electrons change their energy levels in an atom, photons are being absorbed or emitted.



Note how the engineers' responses to "The photon is a part of the nucleus in an atom." slope down steeply to the right, while the tech students' and the ns—ne students' responses are roughly flat.

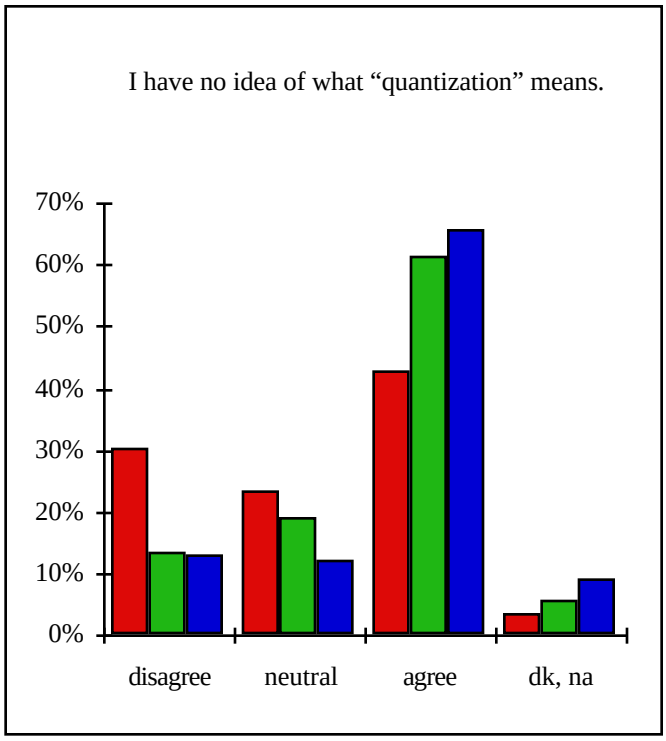
The photon is part of the nucleus in an atom.



			N	disagree strongly disagree	agree strongly agree	**asa-dsd**
18 BC	The photon is a part of the nucleus in an atom.	engineers	112	52%	12%	**-40%**
		tech students	52	33%	37%	4%
		ns—ne	108	39%	23%	-16%
		total	272	43%	21%	**-22%**

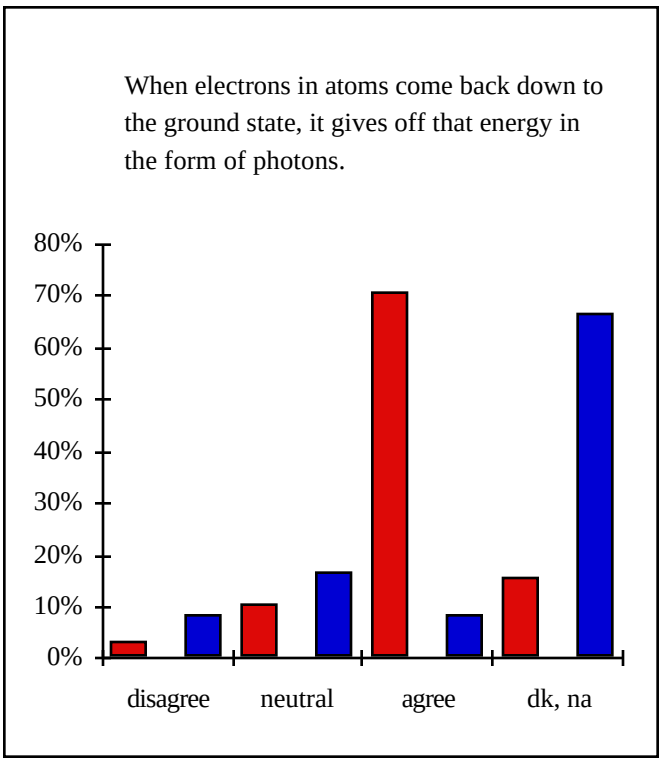
The engineering students are somewhat more confident than the others they know what quantization means in the questions, even though we have not yet taught this in physics (perhaps they learned it in high school or in chemistry).

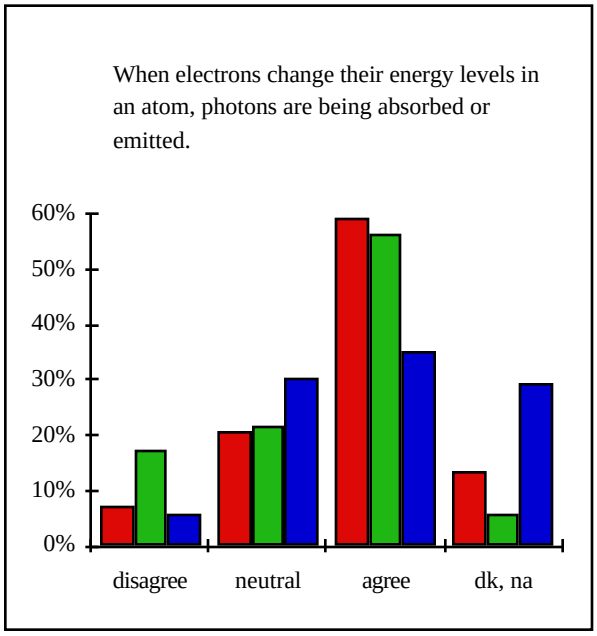
I have no idea what “quantization” means.



			N	disagree strongly disagree	agree strongly agree	**asa-dsd** **-40%**
24 BC	I have no idea of what “quantization” means.	engineers	112	30%	43%	13%
		tech students	52	13%	62%	**48%**
		ns—ne	108	13%	66%	**53%**
		total	272	20%	56%	**35%**

When electrons in atoms come back down to the ground state, it gives off energy in the form of photons. (left)





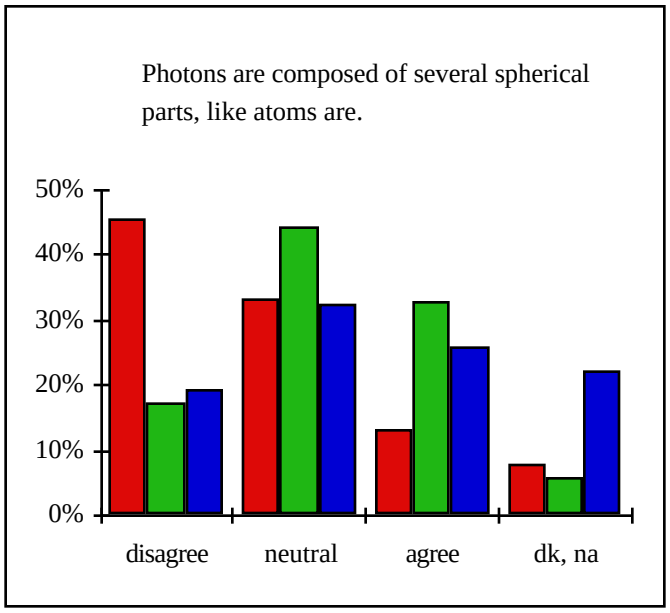
When electrons change their energy levels in an atom, photons are being absorbed or emitted. (right)

			N	disagree strongly disagree	agree strongly agree	asa-dsd
40 A	When electrons in atoms come back down to the ground state, it gives off that energy in the form of photons.	engineers	58	3%	71%	**67%**
		tech students				
		ns—ne	12	8%	8%	0%
		total	70	4%	60%	**56%**

			N	disagree strongly disagree	agree strongly agree	asa-dsd
32	When electrons change their energy levels in an atom, photons are being absorbed or emitted.	engineers	170	7%	59%	**52%**
		tech students	52	17%	56%	**38%**
		ns—ne	120	6%	35%	**29%**
		total	342	8%	50%	**42%**

Engineering students can also recognize that photons are not protons in greater numbers than the tech students and ns—ne students.

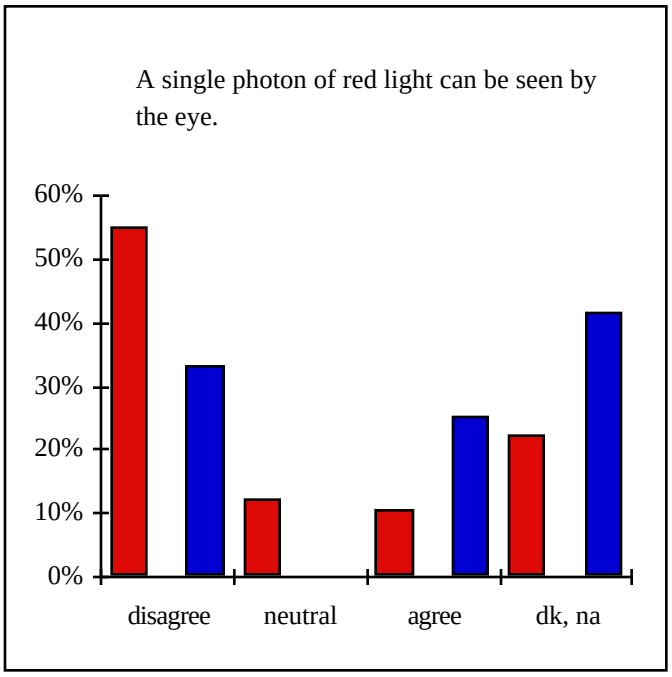
Photons are composed of several spherical parts, like atoms are.



			N	disagree strongly disagree	agree strongly agree	**asa-dsd**
27 BC	Photons are composed of several spherical parts, like atoms are.	engineers	112	46%	13%	**-32%**
		tech students	52	17%	33%	**15%**
		ns—ne	108	19%	26%	6%
		total	272	30%	22%	-8%

Engineers are more likely to recognize that a detector must be awfully sensitive to detect just one photon.

A single photon of red light can be seen by the eye.

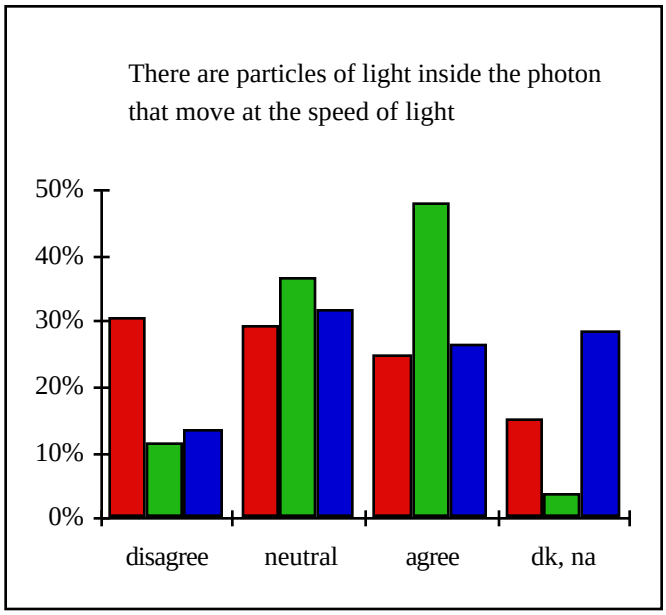


			N	disagree strongly disagree	agree strongly agree	**asa-dsd**
19 A	A single photon of red light can be seen by the eye.	engineers	58	55%	10%	**-45%**
		tech students				
		ns—ne	12	33%	25%	-8%
		total	70	51%	13%	**-39%**

But engineering students are not always on top of correct ideas:

A surprise to us was the answer to the question of whether photons are composite or not. Most students (engineers, tech students, ns—ne) chose to be neutral or to agree than to disagree. Engineers do see photons slightly more as things in themselves than ns—ne students or, especially, tech students, having a flat distribution rather than one canted upward toward the right.

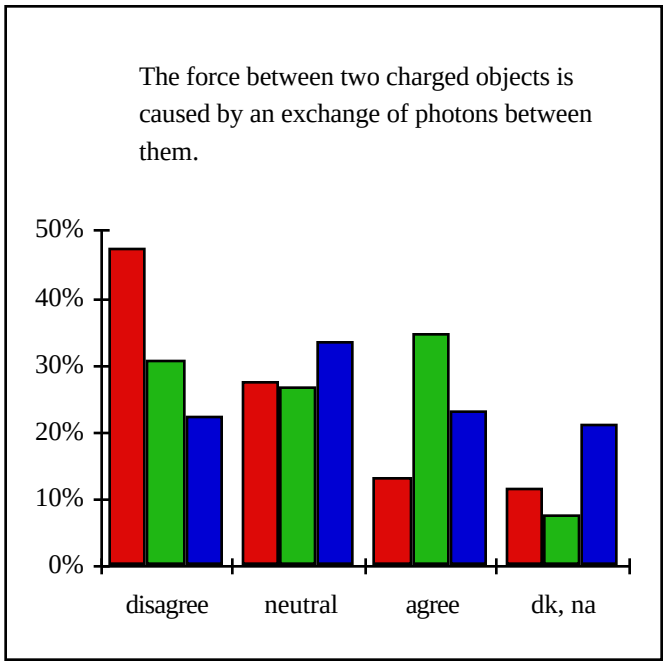
There are particles of light inside the photon that move at the speed of light.



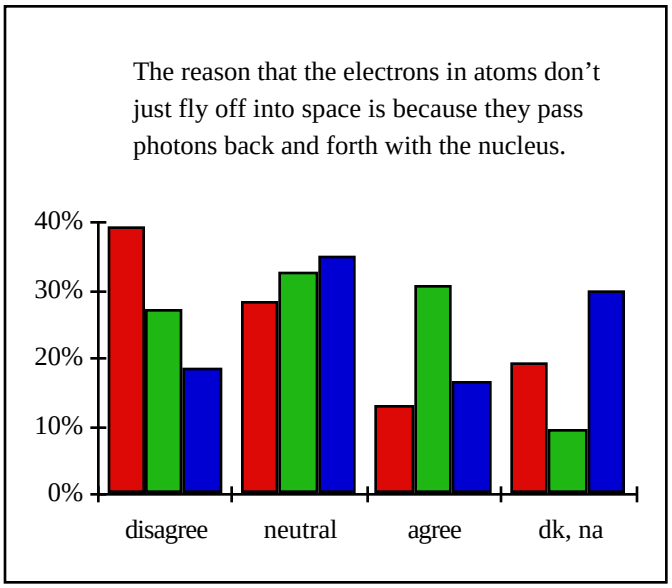
			N	disagree strongly disagree	agree strongly agree	**asa-dsd** **-42%**
37	There are particles of light inside the photon that move at the speed of light	engineers	170	31%	25%	-6%
		tech students	52	12%	48%	**37%**
		ns—ne	120	13%	27%	13%
		total	342	22%	29%	7%

Most introductory physics courses apparently do not convince students that gauge bosons rule the world. Note that engineers do worse than the other students here.

The force between two charged objects is caused by an exchange of photons between them.

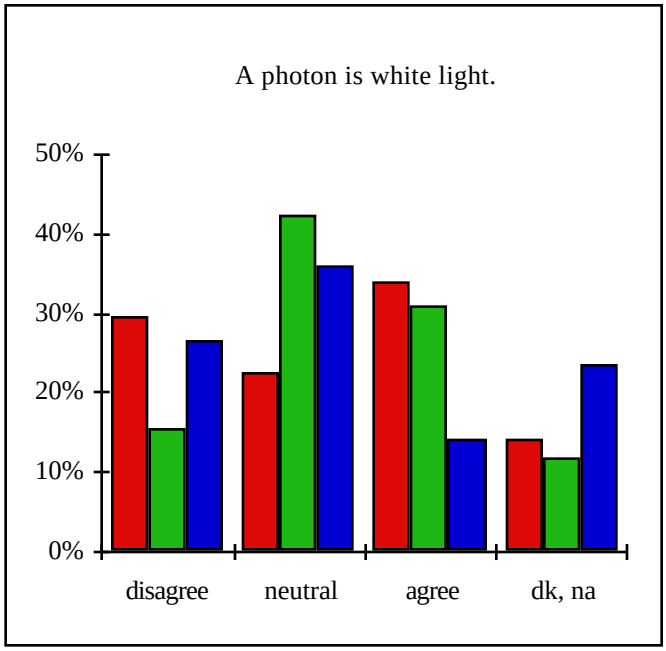


The reason that the electrons in atoms don’t just fly off into space is because they pass photons back and forth with the nucleus.



We asked a multiple choice question about students' mental images of the photon. Overall, 22.5% chose "a ball of light" as an answer. Perhaps in their minds, the ball is *white*, except that only 3.5% chose "a ball of some kind that's always white in color." We have no idea how these are seen as consistent. The ns—ne students appear to have the better idea here.

A photon is white light.



			N	disagree strongly disagree	agree strongly agree	**asa-dsd**
30, 29	A photon is white light.	engineers	170	29%	34%	5%
		tech students	52	15%	31%	**15%**
		ns—ne	120	27%	14%	**-13%**
		total	342	26%	27%	0%

The AJP paper of Ambrose, Shaffer, Steinberg, and McDermott (*Am. J. Phys.* **67**, 146 (1999)) suggested that students view slits as acting to "chop off" waves or particles going through the slits.

You may have seen their figures:

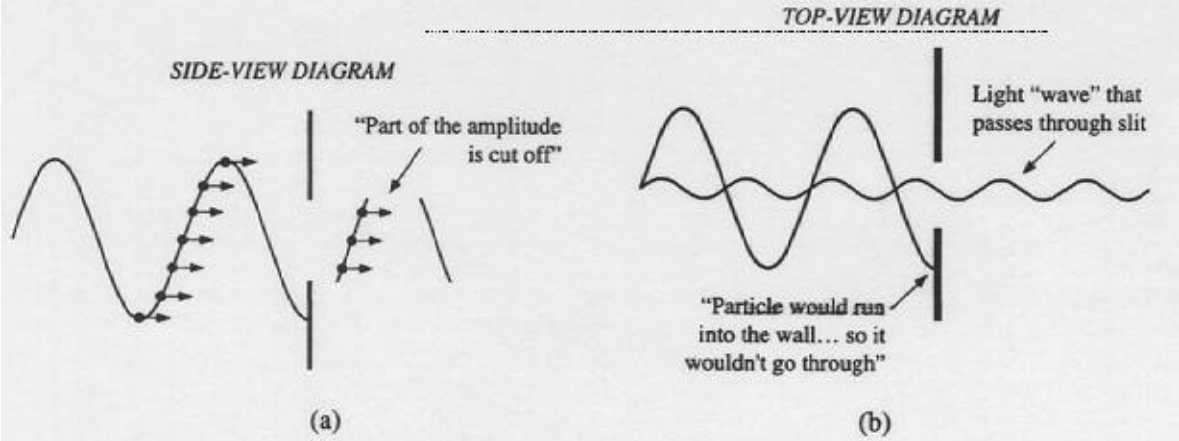
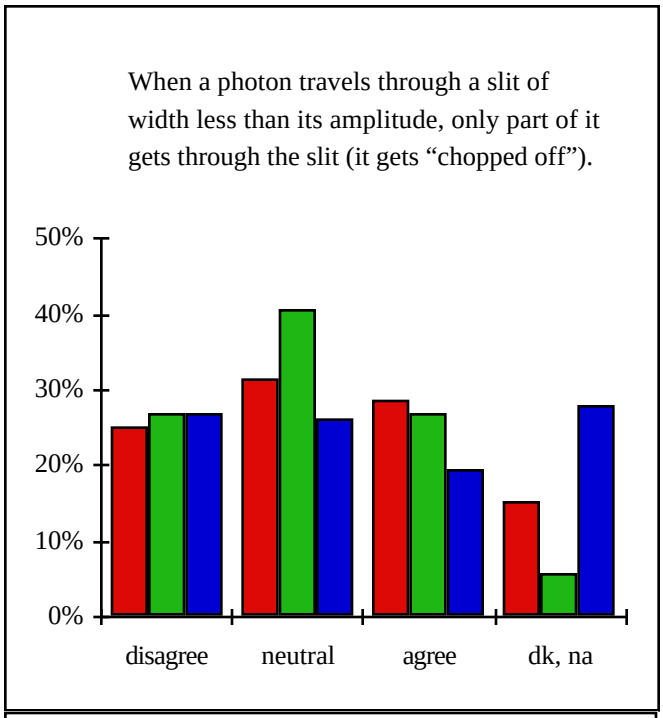
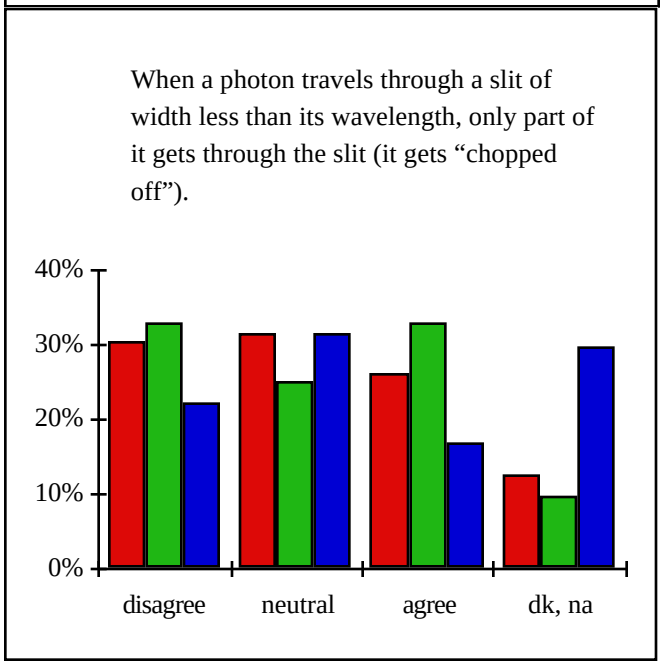


Fig. 7. Representative diagrams drawn by various modern physics students who believed that photons travel along sinusoidal paths. One student drew the diagram in (a) while trying to account for diffraction. The student referred to each dot as a "photon." Another student drew the diagram in (b) while trying to account for polarization.

We asked about this mental picture in versions B and C of our survey. The questions are:

When a photon travels through a slit of width less than its amplitude (top)/wavelength (bottom), only part of it gets through the slit (it gets “chopped off”).





About a quarter of the students we interviewed definitely **agreed**, while only a quarter definitely **disagreed**.

SUMMARY:

- Students are not blank slates.

- Engineering students apparently do have more sophisticated ideas about quantization than tech students or non-science—non-engineering students.

- Incorrect ideas abound among all groups of students studied.

- A significant number of students believe that slits physically *trim* the wave or particle going through them.