Clicker Questions

Modern Physics

Chapter 3: "The Quantum Revolution I: From Light Waves to Photons"

Cambridge University Press
felderbooks.com

by Gary Felder and Kenny Felder

Instructions

- These questions are offered in two formats: a deck of PowerPoint slides, and a PDF file. The two files contain identical contents. There are similar files for each of the 14 chapters in the book, for a total of 28 files.
- Each question is marked as a "Quick Check" or "ConcepTest."
  - Quick Checks are questions that most students should be able to answer correctly if they have done the reading or followed the lecture. You can use them to make sure students are where you think they are before you move on.
  - ConcepTests (a term coined by Eric Mazur) are intended to stimulate debate, so you don't want to prep the class too explicitly before asking them. Ideally you want between 30% and 80% of the class to answer correctly.
- Either way, if a strong majority answers correctly, you can briefly discuss the answer and move on. If many students do not answer correctly, consider having them talk briefly in pairs or small groups and then vote again. You may be surprised at how much a minute of unguided discussion improves the hit rate.
- Each question is shown on two slides: the first shows only the question, and the second adds the correct answer.
- Some of these questions are also included in the book under "Conceptual Questions and ConcepTests," but this file contains additional questions that are not in the book.
- Some of the pages contain multiple questions with the same set of options. These questions are numbered as separate questions on the page.
- Some questions can have multiple answers. (These are all clearly marked with the phrase "Choose all that apply.") If you are using a clicker system that doesn't allow multiple responses, you can ask each part separately as a yes-or-no question.

3.1 Math Interlude: Interference

Two waves meet, and in one particular point there is "constructive interference." What does that mean? (Choose one.)

A. The two waves experience linear superposition.

B. The resulting wave at that point has higher highs (more positive), and lower lows (more negative), than the individual waves.

C. The resulting wave at that point has higher highs (more positive) than the individual waves. The lows are *less* negative, or may not exist at all.

Two waves meet, and in one particular point there is "constructive interference." What does that mean? (Choose one.)

A. The two waves experience linear superposition.

B. The resulting wave at that point has higher highs (more positive), and lower lows (more negative), than the individual waves.

C. The resulting wave at that point has higher highs (more positive) than the individual waves. The lows are *less* negative, or may not exist at all.

Solution: B

Two electromagnetic waves $E_1(x)$ and $E_2(x)$ meet at a point. But this occurs in a medium (such as air or water), not in a vacuum, so the waves do *not* perfectly obey linear superposition. What does that mean? (Choose one.)

A. The resulting field at that point may be something other than $E_1(x) + E_2(x)$.

B. The waves do not interfere with each other.

C. It's impossible for the waves to interfere destructively.

D. No matter where they meet, the two waves will cancel each other out.

Two electromagnetic waves $E_1(x)$ and $E_2(x)$ meet at a point. But this occurs in a medium (such as air or water), not in a vacuum, so the waves do *not* perfectly obey linear superposition. What does that mean? (Choose one.)

A. The resulting field at that point may be something other than $E_1(x) + E_2(x)$.

B. The waves do not interfere with each other.

C. It's impossible for the waves to interfere destructively.

D. No matter where they meet, the two waves will cancel each other out.

Solution: A

Two points on the surface of a lake both emit identical waves (ripples up and down, radiating outward). Looking at a third point on the lake, you notice that it isn't moving at all. This is because. . . (Choose one.)

A. The only possible explanation is that the third point is very far away from the two wave sources.

B. Because of the geometry of how ripples spread out, certain points will never be touched by either circular wave.

C. When both circular waves reach that point, their effects cancel out.

Two points on the surface of a lake both emit identical waves (ripples up and down, radiating outward). Looking at a third point on the lake, you notice that it isn't moving at all. This is because... (Choose one.)

A. The only possible explanation is that the third point is very far away from the two wave sources.

B. Because of the geometry of how ripples spread out, certain points will never be touched by either circular wave.

C. When both circular waves reach that point, their effects cancel out.

Solution: C

If you increase the frequency of a regular sine wave, which of the following happens? (Choose one.)

A. The period increases.

B. The period decreases.

C. The amplitude increases.

D. The amplitude decreases.

If you increase the frequency of a regular sine wave, which of the following happens? (Choose one.)

A. The period increases.

B. The period decreases.

C. The amplitude increases.

D. The amplitude decreases.

Solution: B

Two strings are both oscillating. At each moment each string looks like a sine wave. The two oscillating strings have the same wavelength, but String A has a higher frequency than String B. What does that imply about their oscillations? (Choose all that apply.)

A. If you look at a particular moment the peaks on String A are closer together than the ones on String B.

B. If you look at a particular moment the peaks on String B are closer together than the ones on String A.

C. If you watch over time, String A completes a full up-and-down cycle faster than String B.

D. If you watch over time, String B completes a full up-and-down cycle faster than String A.

Two strings are both oscillating. At each moment each string looks like a sine wave. The two oscillating strings have the same wavelength, but String A has a higher frequency than String B. What does that imply about their oscillations? (Choose all that apply.)

A. If you look at a particular moment the peaks on String A are closer together than the ones on String B.

B. If you look at a particular moment the peaks on String B are closer together than the ones on String A.

C. If you watch over time, String A completes a full up-and-down cycle faster than String B.

D. If you watch over time, String B completes a full up-and-down cycle faster than String A.

Solution: C

Two sources emit sine waves. You have found a perfect node: a place where these two waves cancel perfectly, so the net effect at your spot is nothing at all, no matter how long you keep watching. Which of the following can you reasonably conclude? (Choose all that apply.)

A. The two sources must be emitting at the same frequency.

B. The two sources must be emitting at the same amplitude.

C. The two sources must be emitting at the same phase.

Two sources emit sine waves. You have found a perfect node: a place where these two waves cancel perfectly, so the net effect at your spot is nothing at all, no matter how long you keep watching. Which of the following can you reasonably conclude? (Choose all that apply.)

A. The two sources must be emitting at the same frequency.

B. The two sources must be emitting at the same amplitude.

C. The two sources must be emitting at the same phase.

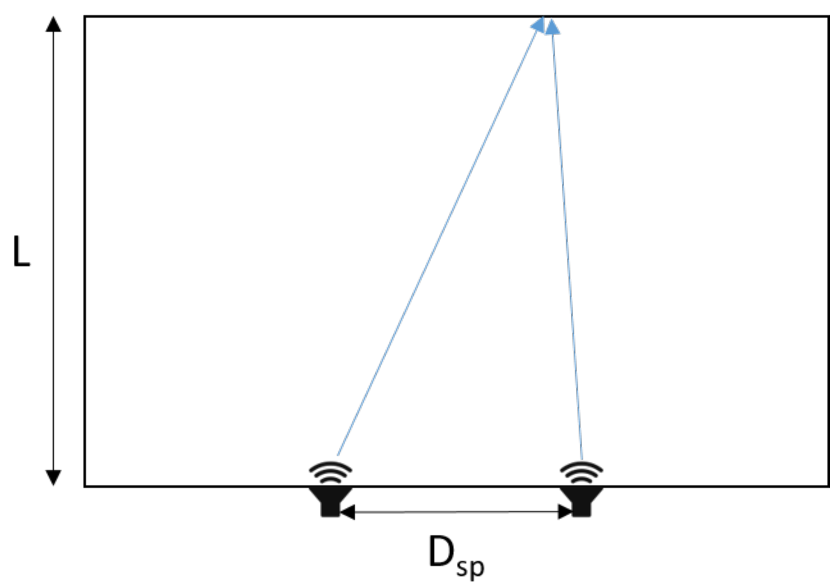
Solution: A and B

Crowds at sporting events often simulate a wave as follows. A few fans stand up. As they sit down, the people to their right stand up. As that group sits down, the people to their right stand up, and so on. The visual effect, from a distance, is of a wave rippling through the crowd. Now, suppose a fan at the far left of the stadium starts a wave that propagates to the right, while a fan at the far right starts a wave that propagates to the left. When the two waves meet in the middle, will they obey the law of linear superposition A) exactly, B) approximately, or C) not at all?

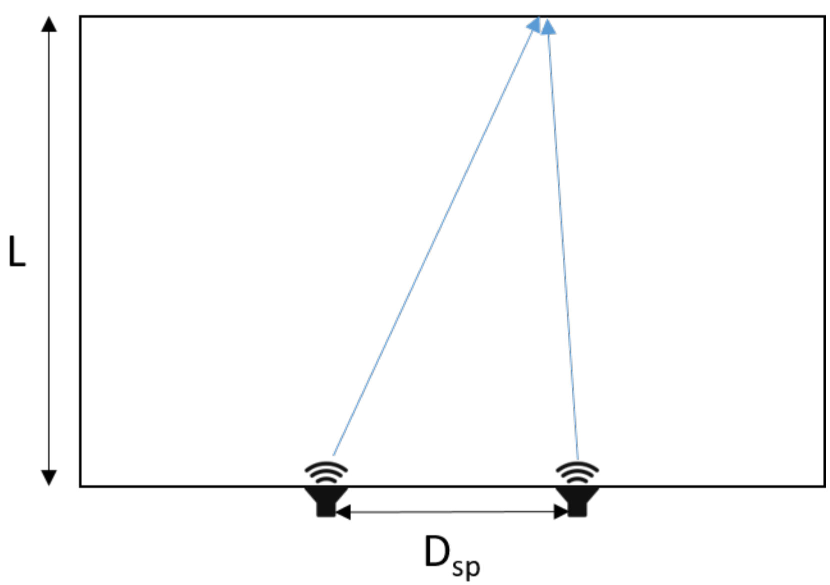
Crowds at sporting events often simulate a wave as follows. A few fans stand up. As they sit down, the people to their right stand up. As that group sits down, the people to their right stand up, and so on. The visual effect, from a distance, is of a wave rippling through the crowd. Now, suppose a fan at the far left of the stadium starts a wave that propagates to the right, while a fan at the far right starts a wave that propagates to the left. When the two waves meet in the middle, will they obey the law of linear superposition A) exactly, B) approximately, or C) not at all?

Solution: C. They will not even approximately obey linear superposition because nobody is going to get any higher than just standing, so if each wave results in "standing" at a certain point the result will just be "standing," not two times standing.

The image below shows two speakers emitting sound waves of the same wavelength λ and the same initial phase. Let Point A be the point halfway between the two speakers, and let Point B be the point opposite Point A on the far wall. Is there any combination of D_{sp}, L, and λ for which the two waves would interfere destructively at Point B?



The image below shows two speakers emitting sound waves of the same wavelength λ and the same initial phase. Let Point A be the point halfway between the two speakers, and let Point B be the point opposite Point A on the far wall. Is there any combination of D_{sp}, L, and λ for which the two waves would interfere destructively at Point B?



Solution: No. For any non-zero values of those quantities, the two waves will travel exactly the same distance as each other. So if the two waves start in phase, the will reach this point in phase.

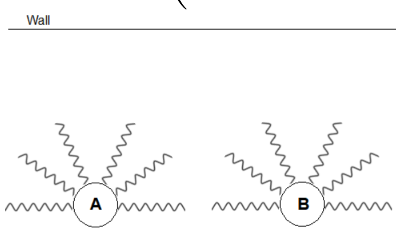
Alice shakes her end of the rope repeatedly, sending a sine wave traveling down the rope to the other end. Bob does the same thing on his end, sending a traveling wave towards Alice. True or false: If they time their shaking just right they can get completely destructive interference so the whole rope just stays flat, never moving.

Alice shakes her end of the rope repeatedly, sending a sine wave traveling down the rope to the other end. Bob does the same thing on his end, sending a traveling wave towards Alice. True or false: If they time their shaking just right they can get completely destructive interference so the whole rope just stays flat, never moving.

Solution: False.

Alice's peaks are moving right and Bob's are moving left. If at some moment her peaks line up with his troughs to create completely destructive interference then a moment later they will not line up, so the rope cannot stay flat.

Source A emits light of only one frequency, radiating outward in a sphere. Source B emits light of that same frequency, also radiating out from itself in a sphere. Light from both sources hits the wall. Will you see constructive or destructive interference on the back wall? (Choose one.)



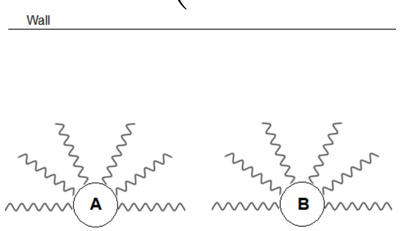
A. Only constructive interference (bright light).

B. Only destructive interference (dim or no light).

C. Constructive interference in some places, destructive in others (some regions of bright light, some of dim).

D. The answer depends on the placement of the sources and their relative phases.

Source A emits light of only one frequency, radiating outward in a sphere. Source B emits light of that same frequency, also radiating out from itself in a sphere. Light from both sources hits the wall. Will you see constructive or destructive interference on the back wall? (Choose one.)



A. Only constructive interference (bright light).

B. Only destructive interference (dim or no light).

C. Constructive interference in some places, destructive in others (some regions of bright light, some of dim).

D. The answer depends on the placement of the sources and their relative phases.

Solution: C

3.2 The Young Double-Slit Experiment

Running the double-slit experiment with light, you identify a particular point on the back wall as a local maximum of brightness. What do you conclude? (Choose one.)

A. The paths from the two slits to this point are the same length as each other.

B. Those two paths may differ, but they differ by an integer multiple of the light wavelength.

C. Those two paths may differ, but they differ by an integer multiple of the light wavelength plus half a wavelength.

D. The distance from this point to each slit is the same as the frequency of the light.

Running the double-slit experiment with light, you identify a particular point on the back wall as a local maximum of brightness. What do you conclude? (Choose one.)

A. The paths from the two slits to this point are the same length as each other.

B. Those two paths may differ, but they differ by an integer multiple of the light wavelength.

C. Those two paths may differ, but they differ by an integer multiple of the light wavelength plus half a wavelength.

D. The distance from this point to each slit is the same as the frequency of the light.

Solution: B

The evil scientist Dr. Horrible is experimenting with his new "Freeze Ray," the red beam that comes out of his nefarious weapon. Firing the Freeze Ray into a double-slit experiment, he finds alternating bands of light (red) and dark (no red). What does he conclude? (Choose one.)

A. The Freeze Ray is a wave.

B. The Freeze Ray is a particle beam.

C. Crime doesn't pay.

The evil scientist Dr. Horrible is experimenting with his new "Freeze Ray," the red beam that comes out of his nefarious weapon. Firing the Freeze Ray into a double-slit experiment, he finds alternating bands of light (red) and dark (no red). What does he conclude? (Choose one.)

A. The Freeze Ray is a wave.

B. The Freeze Ray is a particle beam.

C. Crime doesn't pay.

Solution: A

In a double-slit experiment, waves (such as water waves or light) show bright and dark fringes. Which of the following is the reason particles (like bullets) don't show these fringes? (Choose one.)

A. The bullets collide with each other and that messes up the pattern.

B. When two streams of bullets merge, the resulting stream always has more bullets than either stream alone, never fewer.

C. Waves spread out more uniformly than bullets.

D. Bullets actually do show the same pattern as water waves.

In a double-slit experiment, waves (such as water waves or light) show bright and dark fringes. Which of the following is the reason particles (like bullets) don't show these fringes? (Choose one.)

A. The bullets collide with each other and that messes up the pattern.

B. When two streams of bullets merge, the resulting stream always has more bullets than either stream alone, never fewer.

C. Waves spread out more uniformly than bullets.

D. Bullets actually do show the same pattern as water waves.

Solution: B

If you do a double-slit experiment with light you will see alternating bright and dark spots. True or False: If you cover up one of the slits, the dark spots will become brighter.

If you do a double-slit experiment with light you will see alternating bright and dark spots. True or False: If you cover up one of the slits, the dark spots will become brighter.

Solution: True. Such a spot will still receive light waves from the remaining slit, and this light wave will no longer be canceled out (destructive interference) by waves coming from the slit you covered.

3.3 One Photon at a Time

Which of the following represent fundamental differences between a wave and a particle? (Choose all that apply.)

A. You can measure a particle but you can't detect a wave.

B. Two waves always add up to something less than their individual values, but particles add up to something greater.

C. Two waves might add up to something less or greater than their individual values, but particles always add up to something greater.

D. You can have 9 particles or 10 particles, but not $9\frac{3}{4}$ particles.

Which of the following represent fundamental differences between a wave and a particle? (Choose all that apply.)

A. You can measure a particle but you can't detect a wave.

B. Two waves always add up to something less than their individual values, but particles add up to something greater.

C. Two waves might add up to something less or greater than their individual values, but particles always add up to something greater.

D. You can have 9 particles or 10 particles, but not $9\frac{3}{4}$ particles.

Solution: C, D

Isaac Newton viewed light as a stream of particles. What evidence have we seen in this chapter that disproves this view? (Choose one.)

A. A stream of particles would never have dark bands in a double-slit experiment.

B. A stream of particles would not appear as single dots.

Isaac Newton viewed light as a stream of particles. What evidence have we seen in this chapter that disproves this view? (Choose one.)

A. A stream of particles would never have dark bands in a double-slit experiment.

B. A stream of particles would not appear as single dots.

Solution: A

Maxwell's equations describe light as an oscillating electric field and an oscillating magnetic field perpendicular to each other. What evidence have we seen in this chapter that disproves this view? (Choose one.)

A. Oscillating fields would never have dark bands in a double-slit experiment.

B. Oscillating fields would not appear as single dots.

Maxwell's equations describe light as an oscillating electric field and an oscillating magnetic field perpendicular to each other. What evidence have we seen in this chapter that disproves this view? (Choose one.)

A. Oscillating fields would never have dark bands in a double-slit experiment.

B. Oscillating fields would not appear as single dots.

Solution: B

Why do you get dark bands with a wave but never with a particle? (Choose one.)

A. Particles fan out to every spot randomly, but waves follow a mathematical trajectory that never hits certain spots.

B. Particles are discrete, but waves are continuous.

C. The height of a wave can be positive or negative, but the number of particles can never be negative.

Why do you get dark bands with a wave but never with a particle? (Choose one.)

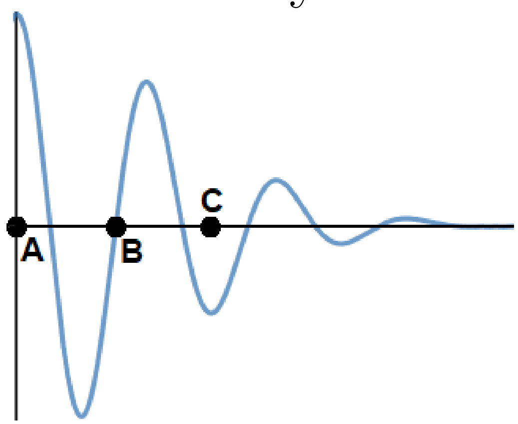
A. Particles fan out to every spot randomly, but waves follow a mathematical trajectory that never hits certain spots.

B. Particles are discrete, but waves are continuous.

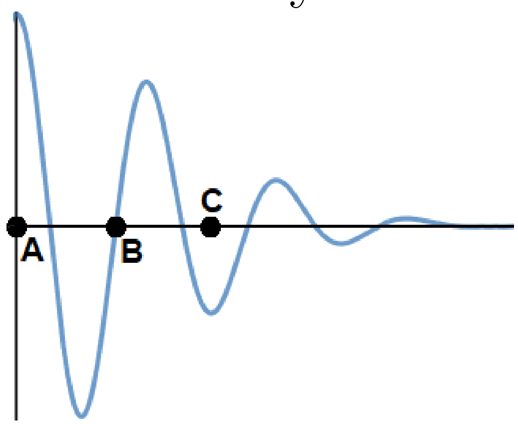
C. The height of a wave can be positive or negative, but the number of particles can never be negative.

Solution: C

A particle is moving along the x-axis. Its wavefunction is shown below. If you measure the position of this particle, where are you most likely to find it: near $x = A$, near $x = B$, or near $x = C$? Where are you least likely to find it?



A particle is moving along the x-axis. Its wavefunction is shown below. If you measure the position of this particle, where are you most likely to find it: near $x = A$, near $x = B$, or near $x = C$? Where are you least likely to find it?



Solution: Most likely: A
Least likely: B

You do a double-slit experiment with light so dim that it goes through one photon at a time. For each of the following situations, would you see A) a particle-like pattern or B) a wave-like pattern (interference fringes)?

1. You put a detector in one of the slits that tells you as a photon passes through that slit.
2. You put that same detector in but nobody looks at the detector to see what it said. You only look at the pattern on the back wall.
3. You put detectors just past the slits so that you can tell which slit the photon came out, but without measuring it at the slit.

You do a double-slit experiment with light so dim that it goes through one photon at a time. For each of the following situations, would you see A) a particle-like pattern or B) a wave-like pattern (interference fringes)?

1. You put a detector in one of the slits that tells you as a photon passes through that slit.

   Solution: A

2. You put that same detector in but nobody looks at the detector to see what it said. You only look at the pattern on the back wall.

   Solution: A

3. You put detectors just past the slits so that you can tell which slit the photon came out, but without measuring it at the slit.

   Solution: A

If you did a triple slit experiment and put a detector in one of the three slits, what would you expect to see on the back wall? (Choose one.)

A. The same interference pattern you would see if you performed a double-slit experiment with no detector.

B. The same basic pattern, but with the darkest regions being only dim rather than completely black.

C. The same basic pattern, but with greater distance between the dark bands.

D. No interference pattern.

If you did a triple slit experiment and put a detector in one of the three slits, what would you expect to see on the back wall? (Choose one.)

A. The same interference pattern you would see if you performed a double-slit experiment with no detector.

B. The same basic pattern, but with the darkest regions being only dim rather than completely black.

C. The same basic pattern, but with greater distance between the dark bands.

D. No interference pattern.

Solution: B. Light that got detected in one slit would form a particle-like pattern and would reach all parts of the back wall, so no parts would be completely dark. Light that wasn't detected at that slit would go through both of the others and create an interference pattern.

3.4 Blackbody Radiation and the Ultraviolet Catastrophe

Suppose, in a particular cavity, the function $E_w(\nu)$ peaks in the red frequencies. Which of the following is true in that cavity? (Choose one.)

A. The energy of each red wave in that cavity is greater than the energy of each blue wave.

B. The total energy of all the combined red waves in that cavity is greater than the total energy of all the combined blue waves in that cavity.

C. The majority of the energy in that cavity is in the red frequencies.

Suppose, in a particular cavity, the function $E_W(\nu)$ peaks in the red frequencies. Which of the following is true in that cavity? (Choose one.)

A. The energy of each red wave in that cavity is greater than the energy of each blue wave.

B. The total energy of all the combined red waves in that cavity is greater than the total energy of all the combined blue waves in that cavity.

C. The majority of the energy in that cavity is in the red frequencies.

Solution: A

Suppose, in a particular cavity, the function $S(\nu)$ peaks in the blue frequencies. Which of the following is true in that cavity? (Choose one.)

A. The energy of each blue wave in that cavity is greater than the energy of each red wave.

B. The total energy of all the combined blue waves in that cavity is greater than the total energy of all the combined red waves in that cavity.

C. The majority of the energy in that cavity is in the blue frequencies.

Suppose, in a particular cavity, the function $S(\nu)$ peaks in the blue frequencies. Which of the following is true in that cavity? (Choose one.)

A. The energy of each blue wave in that cavity is greater than the energy of each red wave.

B. The total energy of all the combined blue waves in that cavity is greater than the total energy of all the combined red waves in that cavity.

C. The majority of the energy in that cavity is in the blue frequencies.

Solution: B

Which of the following statements are true about the radiation in a cavity at equilibrium? (Choose all that apply.)

A. The radiation energy depends on the temperature of the walls.

B. The radiation energy depends on what the walls are made of.

C. Higher frequencies always contribute more to the energy than lower ones.

D. Lower frequencies always contribute more to the energy than higher ones.

Which of the following statements are true about the radiation in a cavity at equilibrium? (Choose all that apply.)

A. The radiation energy depends on the temperature of the walls.

B. The radiation energy depends on what the walls are made of.

C. Higher frequencies always contribute more to the energy than lower ones.

D. Lower frequencies always contribute more to the energy than higher ones.

Solution: A only

Which of the following describes how Planck solved the ultraviolet catastrophe? (Choose one.)

A. He changed the assumptions about how probable different energies are for an electromagnetic wave in a cavity.

B. He changed the assumptions about what energies were possible for an electromagnetic wave in a cavity.

C. He changed the values of the constants used in calculating the spectrum.

D. He introduced one rule that holds at low frequencies and a different one that holds at high frequencies.

Which of the following describes how Planck solved the ultraviolet catastrophe? (Choose one.)

A. He changed the assumptions about how probable different energies are for an electromagnetic wave in a cavity.

B. He changed the assumptions about what energies were possible for an electromagnetic wave in a cavity.

C. He changed the values of the constants used in calculating the spectrum.

D. He introduced one rule that holds at low frequencies and a different one that holds at high frequencies.

Solution: B

Which of the following did Planck quantize? (Choose all that apply.)

A. The frequency of light waves.

B. The amplitude of light waves.

C. The energy of light waves.

Which of the following did Planck quantize? (Choose all that apply.)

A. The frequency of light waves.

B. The amplitude of light waves.

C. The energy of light waves.

Solution: B and C

Which has more possible energies between 0 and 10^{-18} J, A) an infrared wave (low frequency) or B) a green wave (higher frequency)?

Which has more possible energies between 0 and 10^{-18} J, A) an infrared wave (low frequency) or B) a green wave (higher frequency)?

Solution: A

We've discussed two blackbody spectra, the classically predicted (and incorrect) Rayleigh-Jeans spectrum, and the (experimentally accurate) Planck spectrum. For each of the following, say whether it applies to A) only the classical spectrum, B) only the Planck spectrum, or C) both. (All of them will apply to at least one of the spectra.)

1. It goes to zero in the limit $\nu \to 0$.
2. It goes to zero in the limit $\nu \to \infty$.
3. It has a maximum value.
4. It predicts that higher frequencies always carry more energy than lower ones.
5. It has units of energy per volume per frequency.

We've discussed two blackbody spectra, the classically predicted (and incorrect) Rayleigh-Jeans spectrum, and the (experimentally accurate) Planck spectrum. For each of the following, say whether it applies to A) only the classical spectrum, B) only the Planck spectrum, or C) both. (All of them will apply to at least one of the spectra.)

1. It goes to zero in the limit $\nu \to 0$.

   Solution: C

2. It goes to zero in the limit $\nu \to \infty$.

   Solution: B

3. It has a maximum value.

   Solution: B

4. It predicts that higher frequencies always carry more energy than lower ones.

   Solution: A

5. It has units of energy per volume per frequency.

   Solution: C

For each hypothetical quantization scheme below say whether it would avoid the ultraviolet catastrophe. (Of course Planck's is the only one that not only avoids catastrophe but also correctly matches observed data.) In each case assume h is a constant with appropriate units for that scheme.

1. $\Delta E = 1$ J
2. $\Delta E = k_B T$
3. $\Delta E = h\nu^2$
4. $\Delta E = h/\nu$

For each hypothetical quantization scheme below say whether it would avoid the ultraviolet catastrophe. (Of course Planck's is the only one that not only avoids catastrophe but also correctly matches observed data.) In each case assume h is a constant with appropriate units for that scheme.

1. $\Delta E = 1$ J

   Solution: No. A frequency-independent ΔE would still lead to a frequency-independent $E_w(\nu)$, and thus to an $S(\nu)$ that scales like ν^2, and thus to a ρ that diverges.

2. $\Delta E = k_B T$

   Solution: No, for the same reason as the previous.

3. $\Delta E = h\nu^2$

   Solution: Yes. It might not perfectly match the data, but it would drive results down to zero for high frequency—even faster than Planck's solution did, in fact—so the resulting integral would not blow up.

4. $\Delta E = h/\nu$

   Solution: No. High frequencies would have even higher E_w values, which is even more catastrophic!

3.5 The Photoelectric Effect

You shine light of unknown frequency on Plate A in a photoelectric experiment and you measure the stopping potential required to drop the observed current to zero. The value of that stopping potential tells you which one of the following? (Choose one.)

A. The work function of the material.

B. The maximum energy required to liberate an electron from Plate A

C. The maximum kinetic energy with which any electron leaves Plate A.

You shine light of unknown frequency on Plate A in a photoelectric experiment and you measure the stopping potential required to drop the observed current to zero. The value of that stopping potential tells you which one of the following? (Choose one.)

A. The work function of the material.

B. The maximum energy required to liberate an electron from Plate A

C. The maximum kinetic energy with which any electron leaves Plate A.

Solution: C

Suppose an electron absorbs from a photon an energy that is greater than w for that electron, but less than $(w + Ve)$. Which of the following best describes what will happen? (Choose one.)

A. It will not be liberated from Plate A.

B. It will be liberated from Plate A, but then it will be pulled back to Plate A by the electric force in the vacuum.

C. It will be liberated from Plate A, cross to Plate B, and be registered in the ammeter.

Suppose an electron absorbs from a photon an energy that is greater than w for that electron, but less than $(w + Ve)$. Which of the following best describes what will happen? (Choose one.)

A. It will not be liberated from Plate A.

B. It will be liberated from Plate A, but then it will be pulled back to Plate A by the electric force in the vacuum.

C. It will be liberated from Plate A, cross to Plate B, and be registered in the ammeter.

Solution: B

For each part of this question, choose *one* of the following three options.
A: Predicted by the classical model only (but does not work)
B: Predicted by the photon model only (and does work)
C: Predicted by the classical and photon models (and does work)

1. Some electrons leave Plate A with insufficient energy to overcome the potential difference. These electrons cause no measurable current.
2. Doubling the intensity of the light (without changing the frequency) doubles the current.
3. Below a certain frequency of light, no current flows.
4. The energy of the light is gradually transferred to the electrons, resulting in a small but measurable delay before the current starts.

For each part of this question, choose *one* of the following three options.
A: Predicted by the classical model only (but does not work)
B: Predicted by the photon model only (and does work)
C: Predicted by the classical and photon models (and does work)

1. Some electrons leave Plate A with insufficient energy to overcome the potential difference. These electrons cause no measurable current.

   Solution: C

2. Doubling the intensity of the light (without changing the frequency) doubles the current.

   Solution: C

3. Below a certain frequency of light, no current flows.

   Solution: B

4. The energy of the light is gradually transferred to the electrons, resulting in a small but measurable delay before the current starts.

   Solution: A

Which of the following describes a key difference between the classical and quantum models of the photoelectric effect? (Choose one.)

A. In the classical model, increasing the potential difference V reduces the measured current, but in the photon model it does not.

B. In the classical model, some of the light reflects off Plate A instead of being absorbed, but in the photon model it does not.

C. In the classical model, an electron can absorb a little energy and then a little more until it is liberated, but in the quantum model it must be liberated all at once.

Which of the following describes a key difference between the classical and quantum models of the photoelectric effect? (Choose one.)

A. In the classical model, increasing the potential difference V reduces the measured current, but in the photon model it does not.

B. In the classical model, some of the light reflects off Plate A instead of being absorbed, but in the photon model it does not.

C. In the classical model, an electron can absorb a little energy and then a little more until it is liberated, but in the quantum model it must be liberated all at once.

Solution: C

Which emits more photons per second, a 5 Watt red LED bulb or a 5 Watt blue LED bulb?

A. Red

B. Blue

C. The same

Which emits more photons per second, a 5 Watt red LED bulb or a 5 Watt blue LED bulb?

A. Red

B. Blue

C. The same

Solution: red

In the wave model of light, the intensity of radiation from a point source falls off as $1/r^2$ where r is the distance from the source. Would that still be true in the photon model? Why or why not?

In the wave model of light, the intensity of radiation from a point source falls off as $1/r^2$ where r is the distance from the source. Would that still be true in the photon model? Why or why not?

Solution: Yes. One obvious argument is that the intensity *does* in fact fall off as $1/r^2$; that was an established fact in the 19$^{\text{th}}$ century, so if quantum mechanics disagreed, then quantum mechanics would be wrong. But here's an explanation based on the photon model. Imagine a group of photons leaving a source (such as a light bulb, or the sun). Draw a sphere around that source, and then draw a larger sphere around that one. Every photon goes through the inner sphere, and then goes through the outer sphere. But the surface area of the bigger sphere is bigger: $A = 4\pi r^2$. So if the number of photons is the same, and the area has increased like r^2, then the density of photons per area must have gone down like $1/r^2$.

3.6 Further Photon Phenomena

Which has greater momentum, A) a 10 nm photon or B) a 100 nm photon?

Which has greater momentum, A) a 10 nm photon or B) a 100 nm photon?

Solution: A

A photon and an electron have the same momentum. Which one has greater energy: A) Photon, B) Electron, or C) They are equal?

A photon and an electron have the same momentum. Which one has greater energy: A) Photon, B) Electron, or C) They are equal?

Solution: B

In Compton scattering the wavelength of the photon will . . . (Choose one.)

A. Always go up

B. Always go down

C. Sometimes go up and sometimes go down

In Compton scattering the wavelength of the photon will . . . (Choose one.)

A. Always go up

B. Always go down

C. Sometimes go up and sometimes go down

Solution: A

Compton scattering is evidence for the existence of photons because . . . (Choose one.)

A. At $\theta = 0$ it shows no change in wavelength.

B. Classically the outgoing intensity should be the same in all directions.

C. An electron couldn't deflect an incoming wave, only an incoming particle.

D. Classically the outgoing light should always have the same wavelength as the incoming light.

Compton scattering is evidence for the existence of photons because . . . (Choose one.)

A. At $\theta = 0$ it shows no change in wavelength.

B. Classically the outgoing intensity should be the same in all directions.

C. An electron couldn't deflect an incoming wave, only an incoming particle.

D. Classically the outgoing light should always have the same wavelength as the incoming light.

Solution: D

Suppose you do a Compton experiment in which you shine light on a target and measure the shift in wavelength for light that comes out at 135° to the original direction. Then you repeat the experiment with higher frequency incoming light. Will the observed shift be ... (Choose one.)

A. Larger for the higher frequency light

B. Smaller for the higher frequency light

C. The same both times

Suppose you do a Compton experiment in which you shine light on a target and measure the shift in wavelength for light that comes out at $135°$ to the original direction. Then you repeat the experiment with higher frequency incoming light. Will the observed shift be . . . (Choose one.)

A. Larger for the higher frequency light

B. Smaller for the higher frequency light

C. The same both times

Solution: C

Suppose you shine light on a solid target and liberate electrons. Those electrons pass through a vacuum (with no electric field) and strike another target, causing it to emit radiation. Which of the following describes the frequency of that emitted radiation? (Choose one.)

A. It is always larger than the frequency of the initial radiation.

B. It is always the same as the frequency of the initial radiation.

C. It is always smaller than the frequency of the initial radiation.

D. It will sometimes be smaller than the original and sometimes larger.

Suppose you shine light on a solid target and liberate electrons. Those electrons pass through a vacuum (with no electric field) and strike another target, causing it to emit radiation. Which of the following describes the frequency of that emitted radiation? (Choose one.)

A. It is always larger than the frequency of the initial radiation.

B. It is always the same as the frequency of the initial radiation.

C. It is always smaller than the frequency of the initial radiation.

D. It will sometimes be smaller than the original and sometimes larger.

Solution: C

A muon is an elementary particle similar to an electron but about 200 times more massive. If you scattered light off a muon would the shift in the light's wavelength be ... (Choose one.)

A. Larger than it was for scattering off an electron

B. Smaller than it was for scattering off an electron

C. The same as it was for scattering off an electron

A muon is an elementary particle similar to an electron but about 200 times more massive. If you scattered light off a muon would the shift in the light's wavelength be . . . (Choose one.)

A. Larger than it was for scattering off an electron

B. Smaller than it was for scattering off an electron

C. The same as it was for scattering off an electron

Solution: B

When an electron hits a target and releases radiation, why is there a minimum wavelength in the spectrum of that radiation? (Choose one.)

A. Lower wavelengths can't escape the target and get detected.

B. The electron doesn't come in with enough energy to produce a shorter wavelength photon.

C. The atoms carry off all the excess energy.

D. The radiation is produced by the acceleration of the electron and it can't accelerate fast enough to produce shorter wavelength light.

When an electron hits a target and releases radiation, why is there a minimum wavelength in the spectrum of that radiation? (Choose one.)

A. Lower wavelengths can't escape the target and get detected.

B. The electron doesn't come in with enough energy to produce a shorter wavelength photon.

C. The atoms carry off all the excess energy.

D. The radiation is produced by the acceleration of the electron and it can't accelerate fast enough to produce shorter wavelength light.

Solution: B

You fire a beam of electrons into a target and measure the emitted radiation. Which of the following factors will affect the minimum wavelength of emitted light? (Choose all that apply.)

A. The material the target is made of

B. The thickness of the target

C. The incoming energy of the electrons

D. How long you shine the beam on the target

You fire a beam of electrons into a target and measure the emitted radiation. Which of the following factors will affect the minimum wavelength of emitted light? (Choose all that apply.)

A. The material the target is made of

B. The thickness of the target

C. The incoming energy of the electrons

D. How long you shine the beam on the target

Solution: C

In order for a photon to undergo pair production, which of the following must be true about it?

A. It must have at least a certain minimum frequency.

B. It must have at most a certain maximum frequency.

C. Both of the above, meaning it must be within a certain range of frequencies.

In order for a photon to undergo pair production, which of the following must be true about it?

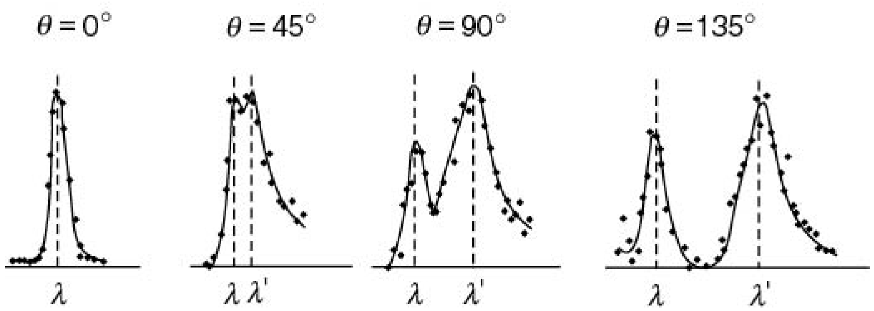
A. It must have at least a certain minimum frequency.

B. It must have at most a certain maximum frequency.

C. Both of the above, meaning it must be within a certain range of frequencies.

Solution: A

In the figure below, the panel showing $\theta = 135°$ shows two peaks, the right one slightly higher but comparable to the left one. If Compton had used much lower frequency incoming light, how would that have affected the relative heights of those two peaks? (Choose one.)

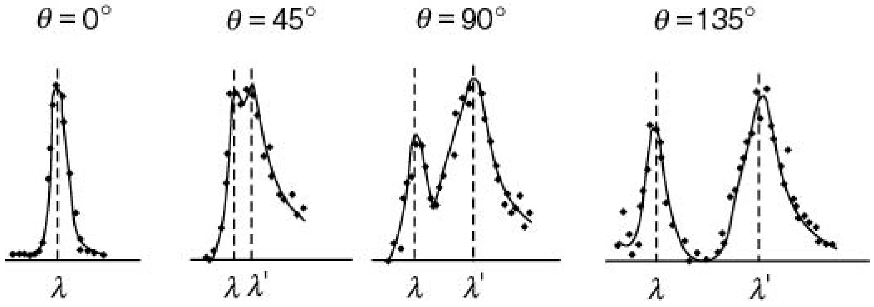


A. The left-hand peak would have been significantly higher than the right-hand peak.

B. The left-hand peak would have been significantly lower than the right-hand peak.

C. The two peaks would still have comparable heights.

In the figure below, the panel showing $\theta = 135°$ shows two peaks, the right one slightly higher but comparable to the left one. If Compton had used much lower frequency incoming light, how would that have affected the relative heights of those two peaks? (Choose one.)



A. The left-hand peak would have been significantly higher than the right-hand peak.

B. The left-hand peak would have been significantly lower than the right-hand peak.

C. The two peaks would still have comparable heights.

Solution: A. The left-hand frequency represents Rayleigh scattering, which occurs when the incoming light collides with a bound electron that remains attached to its atom. The higher the frequency of light the more likely it is that it can knock an electron free, so with lower frequency light he would have seen a higher left peak and a lower right peak.