

Concepts of Physics: Test 3

30 November 2022

Name: _____

Total: **/50**

Instructions

- There are 13 questions on 9 pages.
- Show your reasoning and calculations and always explain your answers.

Physical constants and useful formulae

$$\text{speed} = \frac{\text{distance traveled}}{\text{time elapsed}}$$

$$s = \frac{d}{t}$$

$$\text{frequency} = \frac{1}{\text{time per cycle}}$$

$$f = \frac{1}{T}$$

$$\text{wave speed} = \text{wavelength} \times \text{frequency}$$

$$s = \lambda \times f$$

$$\text{frequency} = \frac{\text{wave speed}}{\text{wavelength}}$$

$$f = \frac{s}{\lambda}$$

$$\text{wavelength} = \frac{\text{wave speed}}{\text{frequency}}$$

$$\lambda = \frac{s}{f}$$

$$\text{speed of light} = 3.0 \times 10^8 \text{ m/s}$$

$$c = 3.0 \times 10^8 \text{ m/s}$$

$$\text{photon energy} = 6.63 \times 10^{-34} \text{ Js} \times \text{frequency}$$

$$E_{\text{photon}} = 6.63 \times 10^{-34} \text{ Js} \times f$$

$$\text{frequency} = \frac{\text{photon energy}}{6.63 \times 10^{-34} \text{ Js}}$$

$$f = \frac{E_{\text{photon}}}{6.63 \times 10^{-34} \text{ Js}}$$

$$\text{photon number} = \frac{\text{total energy}}{\text{photon energy}}$$

$$N = \frac{E}{E_{\text{photon}}}$$

$$\text{total energy} = \text{photon energy} \times \text{photon number}$$

$$E = N \times E_{\text{photon}}$$

$$\text{width central region} = \frac{2 \times \text{wavelength}}{\text{slit width}} \times \text{screen distance}$$

$$w = \frac{2\lambda}{a} d$$

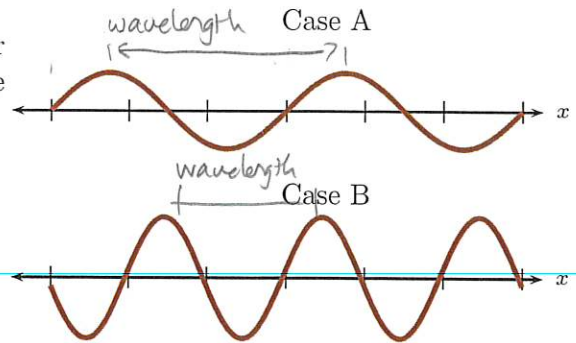
$$\text{particle wavelength} = \frac{6.63 \times 10^{-34} \text{ Js}}{\text{mass} \times \text{speed}}$$

$$\lambda = \frac{6.63 \times 10^{-34} \text{ Js}}{m \times v}$$

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Question 1

Two waves travel on *different* types of string. Their frequencies are identical. A snapshot of each at one moment is illustrated.



- a) Which (choose one) of the following is true?
- i) The wavelength of A is larger than that of B.
 - ii) The wavelength of A is smaller than that of B.
 - iii) The wavelength of A is the same as that of B.

- b) Which (choose one) of the following is true?

- i) The wave speed of A is larger than that of B.
- ii) The wave speed of A is smaller than that of B.
- iii) The wave speed of A is the same as that of B.

larger A
↓
speed = wavelength × freq
↓ same

/3

Question 2

An inventor builds a device which can detect the oscillations associated with electromagnetic waves ~~provided that~~ the frequency of the wave is less than 5.0×10^6 Hz. Will the device detect the oscillations associated with red light, which is an electromagnetic wave traveling with speed 3.0×10^8 m/s and with wavelength 6.32×10^{-7} m? Explain your answer.

$$\text{speed} = \text{wavelength} \times \text{frequency}$$

$$\text{frequency} = \frac{\text{speed}}{\text{wavelength}}$$

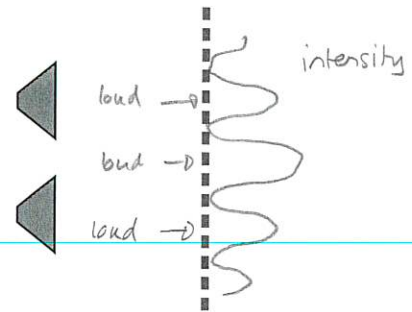
$$= \frac{3 \times 10^8 \text{ m/s}}{6.32 \times 10^{-7} \text{ m}} = 4.7 \times 10^{14} \text{ Hz}$$

This is too high → cannot detect...

/4

Question 3

Two loudspeakers are situated alongside each other. Each plays the same pure note and the sound propagates away from them. A listener moves her ear from top to bottom *along the dashed line*. Which of the following is true regarding the intensity of the sound she hears as she moves her ear?



- i) Same loudness at all locations along the dashed line.
- ii) Loudest at the two locations on the dashed line directly opposite the speakers.
- iii) Loudest midway between the speakers, softer at all other locations.
- iv) Alternating loud and soft at many locations.

actually also consistent

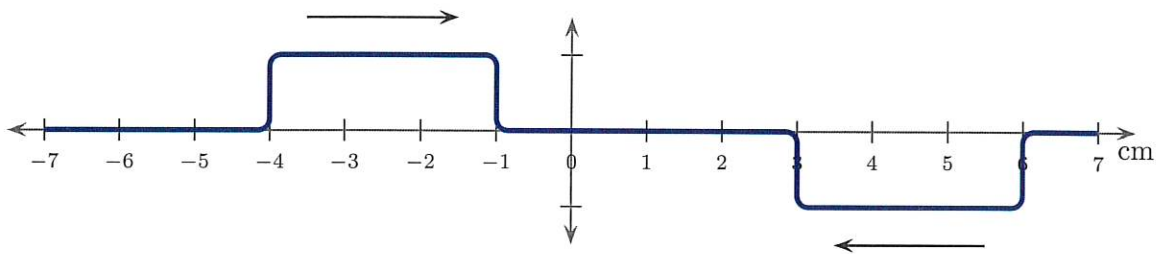
The waves will interfere. In some places they interfere constructively \Rightarrow loud.

In others they interfere destructively \Rightarrow soft.

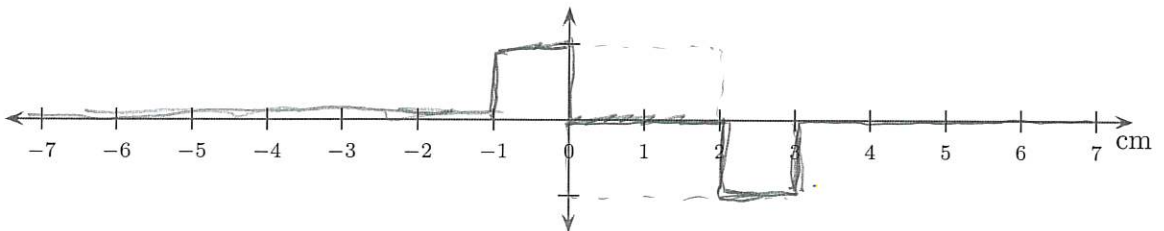
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Question 4

Two wave pulses each move along a string with speed 1 cm/s toward each other. At an initial instant the string appears as illustrated (the grid units are in cm).



Sketch the appearance of the string 3s after the initial instant, using the axes below.



/4

Question 5

A laser pointer produces a beam of red light. The beam does not look like a wave. Describe how you could show that the light produced by the laser can be described in terms of waves. Your description must include: 1) what you would do to the light, 2) what would happen when you do this, 3) why waves describe what happens and 4) why particles cannot describe this.

1) shine light on a pair of closely spaced slits

2) get a pattern of bright / dark spots

3) bright spots result from constructive interference
dark " " " destructive "

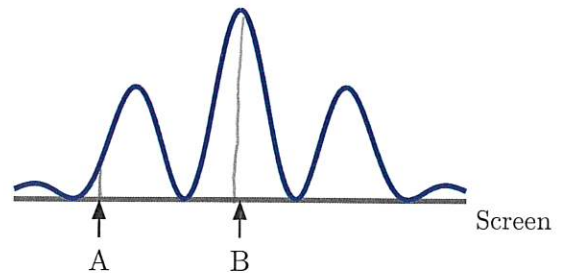
4) particles would just produce two bright spots - don't observe this



/4

Question 6

Light with a definite frequency is fired through a double slit arrangement toward a screen. The intensity of the light at various locations on the screen is indicated by the graph above the screen. Two locations labeled A and B on the screen are as illustrated. Which of the following (choose one) is true concerning any photons that pass through the slits?



- i) Any given photon will never arrive at A but will always arrive at B.
- ii) Any given photon will never arrive at B but will always arrive at A.
- iii) Typically more photons will arrive at A than at B.
- iv) Typically more photons will arrive at B than at A.

intensity \rightarrow probability

larger probability at B than A

/3

Question 7

A red laser produces light with frequency 4.74×10^{14} Hz.

- a) Determine the energy of one photon produced by this laser.

$$E_{\text{photon}} = 6.63 \times 10^{-34} \text{ J}\cdot\text{s} \times 4.74 \times 10^{14} \text{ Hz}$$
$$= 3.1 \times 10^{-19} \text{ J}$$

+2.5

- b) A green laser produces light with a wavelength which is smaller than that produced by the red laser. Describe whether the energy of a single photon produced by the green laser is the same as, smaller than or larger than that of a single photon produced by the red laser. **Explain your answer.**

Need frequency = $\frac{\text{speed light}}{\text{wavelength}}$ ← smaller green } ⇒ frequency larger green

$$E_{\text{photon}} = 6.63 \times 10^{-34} \text{ J}\cdot\text{s} \times \underset{\substack{\uparrow \\ \text{larger green}}}{\text{freq}}$$

⇒ energy green photon larger

/5

Question 8

Two lasers produce red light with exactly the same frequency. However, the intensity (energy produced per second) of the light produced by laser A is much larger than the intensity of the light produced by laser B. Which of the following (choose one) is true?

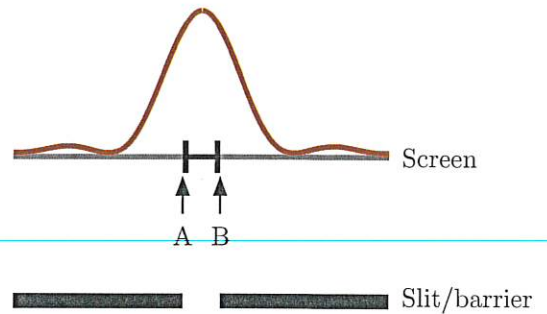
- i) The number of photons produced by A per second is larger than that produced by B; the energy of one photon of A is ~~larger~~ than the energy of one photon of B.
- ii) The number of photons produced by A per second is larger than that produced by B; the energy of one photon of A is the same as the energy of one photon of B.
- iii) The number of photons produced by A per second is the same as that produced by B; the energy of one photon of A is ~~larger~~ than the energy of one photon of B.
- iv) The number of photons produced by A per second is the same as that produced by B; the energy of one photon of A is the same as the energy of one photon of B.

$$\text{number} = \frac{\text{energy total}}{\text{energy photon}} \quad \rightarrow \quad \frac{6.63 \times 10^{-34} \times \text{freq}}{\text{same for A, B}}$$

⇒ number larger for A

Question 9

Neutrons are fired toward a single slit, which is wide enough to accommodate a neutron. A screen is placed beyond the slit and the locations at which neutrons arrive on the screen can be determined. The probability of arrival at various locations on the screen is graphed above the screen on the diagram. A region of the screen is marked from A to B as illustrated; this is exactly opposite the slit. Which of the following (choose one) is true?



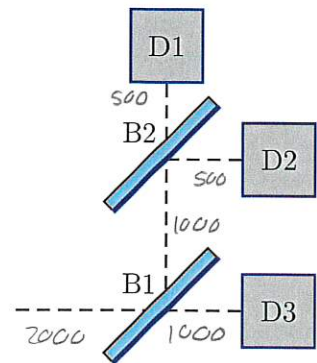
- i) Each individual neutron that passes through the slits definitely arrives in the marked region between A and B.
- ii) Each individual neutron that passes through the slits arrives at many locations.
- iii) Some neutrons that pass through the slits could arrive outside of the region between A and B.

→ a neutron could arrive at any location where prob is not zero. This includes locations /3 outside the A→B region.

Question 10

Laser light is fired from the left towards an arrangement of beam splitters (labeled B1 and B2). Each beamsplitter reflects a photon with probability 1/2 and transmits it with probability 1/2. Three detectors (labeled D1, D2 and D3) are placed beyond the beamsplitters.

- a) Suppose a single photon is fired toward B1 from the left. Which of the following (choose one) is true?
 - i) The photon will be detected in *all* of D1, D2 and D3.
 - ii) The photon will be detected in *both* of D1 and D2 but *not* in D3.
 - iii) The photon will be detected in *one* of D1 or D2 but *not* in D3.
 - iv) The photon will be detected in *one* of D1, D2 and D3.



could take any of the paths / cannot split

- b) Suppose 2000 photons are fired from the left to B1. Approximately how many do you expect to arrive at each detector?

*D1, D2 → 500 each
D3 → 1000*

/5

Question 11

An artificial atom has exactly three energy levels as illustrated. The atom emits photons of light.

$$8.0 \times 10^{-19} \text{ J} \text{ ———}$$

$$6.0 \times 10^{-19} \text{ J} \text{ ———}$$

- a) Determine the largest energy that any photon emitted by the atom could have.

largest change in energy of atom $8 \times 10^{-19} \rightarrow 1 \times 10^{-19}$

atom loses $7 \times 10^{-19} \text{ J}$

$$1.0 \times 10^{-19} \text{ J} \text{ ———}$$

$$\Rightarrow E_{\text{photon}} = 7 \times 10^{-19} \text{ J}$$

- b) Determine the largest frequency of the light that the atom could emit.

$$\text{freq} = \frac{E_{\text{photon}}}{6.63 \times 10^{-34} \text{ J}\cdot\text{s}} = \frac{7 \times 10^{-19} \text{ J}}{6.63 \times 10^{-34} \text{ J}\cdot\text{s}} \quad (\text{need largest } E_{\text{photon}})$$

$$= 1.06 \times 10^{15} \text{ Hz}$$

- c) How many distinct frequencies of light could this atom emit? Explain your answer.

The same as the number of distinct energies atom could lose. These are

$$8 \times 10^{-19} \rightarrow 6 \times 10^{-19} = 2 \times 10^{-19}$$

$$8 \times 10^{-19} \rightarrow 1 \times 10^{-19} = 7 \times 10^{-19}$$

$$6 \times 10^{-19} \rightarrow 1 \times 10^{-19} = 5 \times 10^{-19}$$

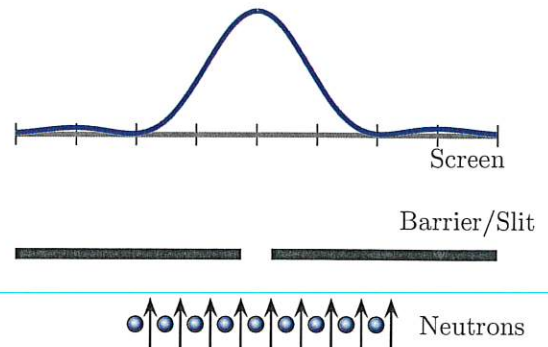
/6

or the number of distinct jumps

three possibilities \Rightarrow 3 frequencies

Question 12

In an experiment, neutrons are fired, one at a time, toward a narrow single slit, which is wide enough to allow neutrons to pass. The neutrons are all fired toward the slit in precisely the same way. The probability distribution for arrival at various locations on a screen is depicted in the diagram below.



- a) Suppose that the experiment is repeated with a second batch of neutrons. This time the neutrons are all fired toward the slit with a larger speed than before. Is the the wavelength of these neutrons (in the second batch) the same as, larger than or smaller than the wavelength of the neutrons in the original experiment? Explain your answer.

$$\text{wavelength} = \frac{6.63 \times 10^{-34}}{\text{speed} \times \text{mass}}$$

larger
=> wavelength smaller

- b) Is the region in which most neutrons arrive on the screen in the experiment with the second batch the same as, wider than or narrower than the region for the original experiment? Explain your answer.

$$\text{width central region} = \frac{2 \times \text{wavelength}}{\text{slit width}} \times \text{screen distance}$$

=> smaller width

/4

Question 13

You are given the atomic spectra for several elements, including sodium, mercury and potassium. You are given an unknown powdered material which you can burn safely. Describe how you could determine whether the powder contains sodium by using the light that is produced when it burns.

- 1) Break the light into its spectrum.
- 2) each element has a distinct spectrum
- 3) compare spectrum obtained to known atomic spectra

/3