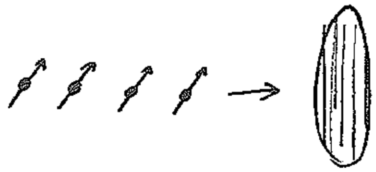
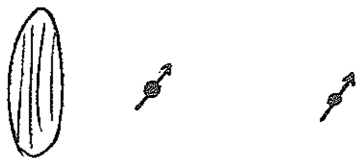
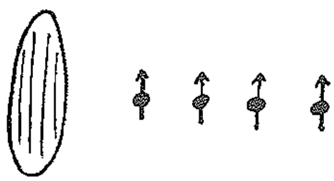
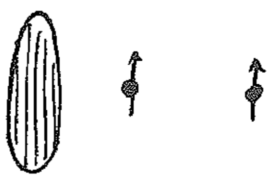
7. 

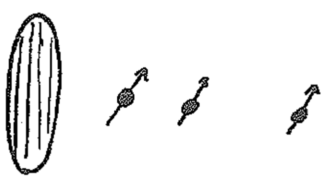
Four equally spaced photons polarized at 45° to the vertical are incident upon a vertically oriented polarizer, as shown. Which of the following pictures represent(s) a possible outcome of this experiment?

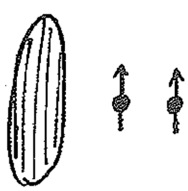
A) 

B) 

GIVE ALL ANSWERS THAT APPLY.

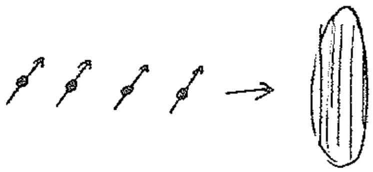
C) 

D) 

E) 

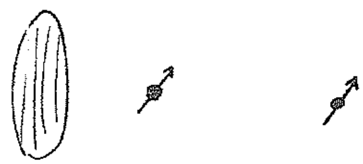
(note: E represents a case where the 1st 2 photons are absorbed & the last 2 are transmitted, while in C, the 2nd and 4th photons are transmitted)

7)

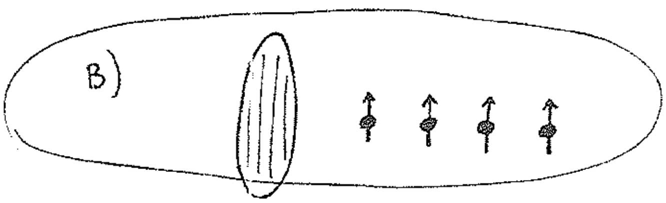


Four equally spaced photons polarized at 45° to the vertical are incident upon a vertically oriented polarizer, as shown. Which of the following pictures represent(s) a possible outcome of this experiment?

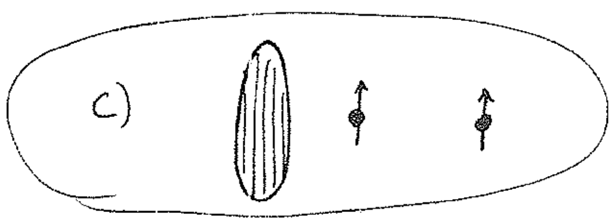
A)



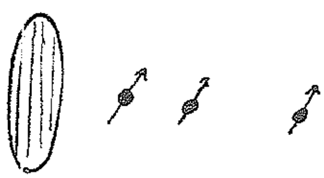
B)



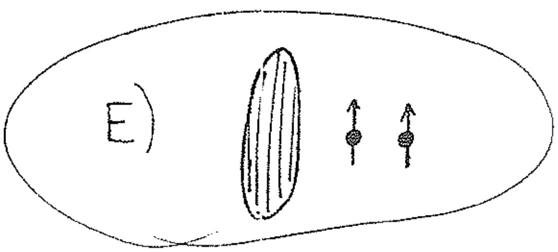
C)



D)



E)



GIVE ALL ANSWERS THAT APPLY.

Photons must be polarized vertically after passing through polarizer, but B, C, and E are all okay, since each photon has some probability of passing through.

(note: E represents a case where the 1st 2 photons are absorbed & the last 2 are transmitted, while in C, the 2nd and 4th photons are transmitted)

Problem 1

The figure above represents the photons in a beam of light with some fixed wavelength and intensity. If size represents photon energy in the picture, which of the pictures below best representes a beam of light with half the wavelength but double the intensity?

A) 

B) 

C) 

D) 

Problem 2

A physicist sets up a series of polarizers and finds that photons which are initially polarized in the vertical direction pass through all the polarizers with a net probability of exactly one quarter. If we send in a beam of vertically polarized light with an intensity 1600 W/m^2 through this series of polarizers, the intensity of the transmitted beam will be

A) 100 W/m^2
B) 400 W/m^2
C) 800 W/m^2
D) 1600 W/m^2
E) 6400 W/m^2

Problem 1

The figure above represents the photons in a beam of light with some fixed wavelength and intensity. If size represents photon energy in the picture, which of the pictures below best representes a beam of light with half the wavelength but double the intensity?

A) 

B) 

C) 

D) 

half wavelength:
$\Rightarrow$ double frequency $\left(f = \frac{c}{\lambda}\right)$
$\Rightarrow$ double energy/photon $(E = hf)$

since each photon has twice the energy, need same #/second to get twice the intensity

Problem 2

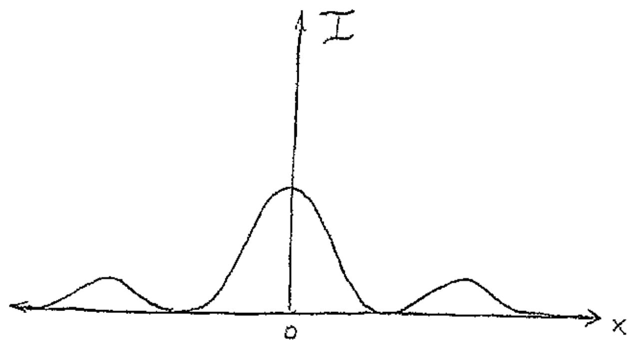
A physicist sets up a series of polarizers and finds that photons which are initially polarized in the vertical direction pass through all the polarizers with a net probability of exactly one quarter. If we send in a beam of vertically polarized light with an intensity 1600 W/m^2 through this series of polarizers, the intensity of the transmitted beam will be

A) 100 W/m^2
B) 400 W/m^2
C) 800 W/m^2
D) 1600 W/m^2
E) 6400 W/m^2

Intensity reduction
= probability that any single photon will go through.

$\therefore I_{transm} = \frac{1}{4} I_0 = 400 \, W/m^2$

Problem 7



The graph shows a plot of intensity versus position on the screen for an interference pattern produced in a double slit experiment with light. If we send four individual photons through the same apparatus, which of the following statements is correct?

A) Two of the photons will hit the screen at $x<0$ and two of the photons will hit the screen at $x>0$.
B) Each photon will hit the screen directly behind one of the slits.
C) The number of photons hitting the screen at $x>0$ could be anything between 0 and 4, but is most likely 2.
D) Since the photons are identical, each photon distributes its energy onto the screen in the same way, with the energy distribution matching the classical intensity pattern.

Problem 8

An electron is in a state $3/5|x_1\rangle - 4/5|x_2\rangle$. If we do a measurement of position, we are most likely to find the electron at

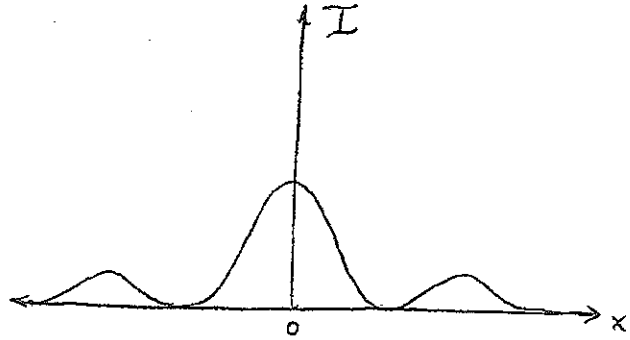
A) x_1
B) x_2
C) $3/5\ x_1 - 4/5\ x_2$
D) $9/25\ x_1 + 16/25\ x_2$
E) All positions between x_1 and x_2 are equally likely.

Problem 9

If we perform the measurement of problem 8 a large number of times on electrons with the same initial state, the average value of the position measurements will be

A) x_1
B) x_2
C) $3/5\ x_1 - 4/5\ x_2$
D) $9/25\ x_1 + 16/25\ x_2$
E) $1/2\ (x_1 + x_2)$

Problem 7



The graph shows a plot of intensity versus position on the screen for an interference pattern produced in a double slit experiment with light. If we send four individual photons through the same apparatus, which of the following statements is correct?

each photon has prob. $\frac{1}{2}$ of hitting region $x>0$.

A) Two of the photons will hit the screen at $x<0$ and two of the photons will hit the screen at $x>0$.
B) Each photon will hit the screen directly behind one of the slits.
C) The number of photons hitting the screen at $x>0$ could be anything between 0 and 4, but is most likely 2.
D) Since the photons are identical, each photon distributes its energy onto the screen in the same way, with the energy distribution matching the classical intensity pattern.

Problem 8

An electron is in a state $3/5|x_1\rangle - 4/5|x_2\rangle$. If we do a measurement of position, we are most likely to find the electron at

Probability $\propto$ squared coefficient
$\left(\frac{4}{5}\right)^2 > \left(\frac{3}{5}\right)^2 \therefore x_2$ most likely.

A) x_1
B) x_2
C) $3/5\ x_1 - 4/5\ x_2$
D) $9/25\ x_1 + 16/25\ x_2$
E) All positions between x_1 and x_2 are equally likely.

Problem 9

If we perform the measurement of problem 8 a large number of times on electrons with the same initial state, the average value of the position measurements will be

get x_1 w. probability $\left(\frac{3}{5}\right)^2 = \frac{9}{25}$
get x_2 w. probability $\left(\frac{-4}{5}\right)^2 = \frac{16}{25}$
Average value: $\frac{9}{25}x_1 + \frac{16}{25}x_2$

A) x_1
B) x_2
C) $3/5\ x_1 - 4/5\ x_2$
D) $9/25\ x_1 + 16/25\ x_2$
E) $1/2\ (x_1 + x_2)$

Problem 4

The figure above represents the photons in a beam of light with some fixed wavelength and intensity. If size represents photon energy in the picture, which of the pictures below best represents a beam of light with the same wavelength but double the intensity?

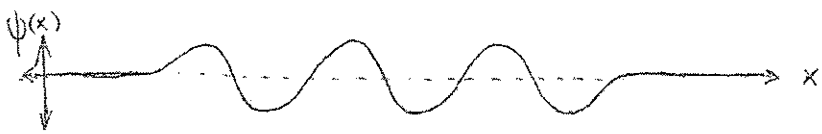
A) 

B) 

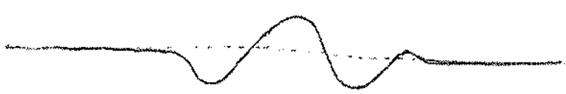
C) 

D) 

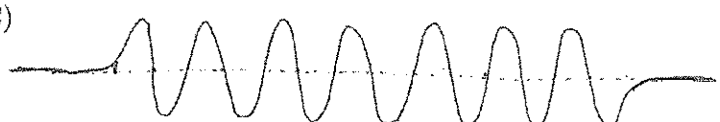
Problem 5

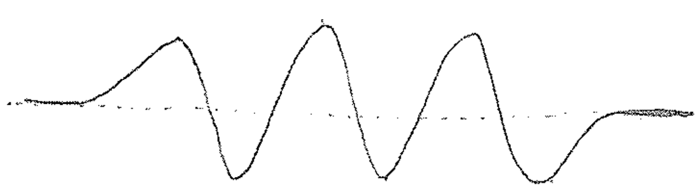


The wavefunction for a traveling electron is described by a wavepacket whose real part is shown above. Which of the following could be the real part of the wavefunction for an electron traveling with double the velocity?

A) 

B) 

C) 

D) 

Problem 4

The figure above represents the photons in a beam of light with some fixed wavelength and intensity. If size represents photon energy in the picture, which of the pictures below best represents a beam of light with the same wavelength but double the intensity?

Same $\lambda \Rightarrow$ Same $f \Rightarrow$ Same energy/photon

A) 

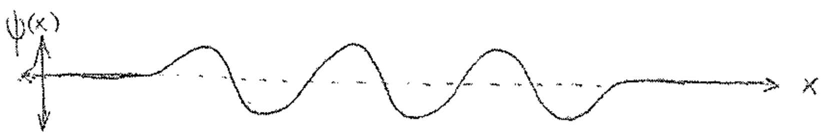
B) 

2x intensity $\Rightarrow$ double energy per time $\Rightarrow$ 2x photons.

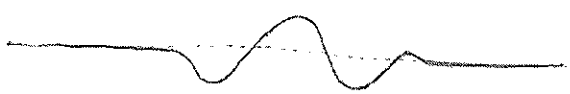
C) 

D) 

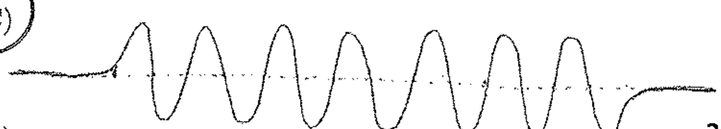
Problem 5

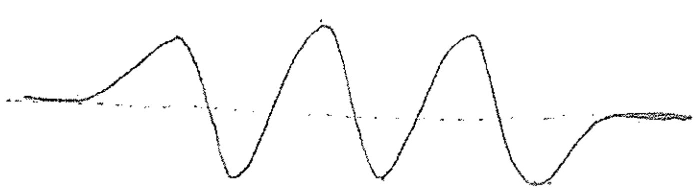


The wavefunction for a traveling electron is described by a wavepacket whose real part is shown above. Which of the following could be the real part of the wavefunction for an electron traveling with double the velocity?

A) 

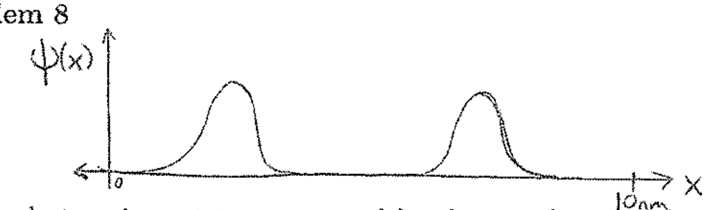
B) 

C) 

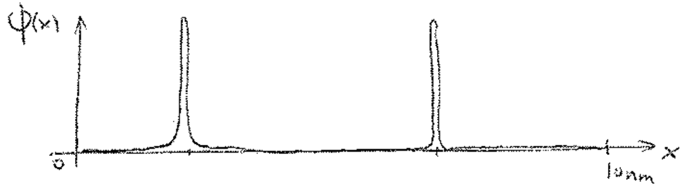
D) 

2x velocity $\Rightarrow$ 2x momentum $\Rightarrow \frac{1}{2}$x wavelength

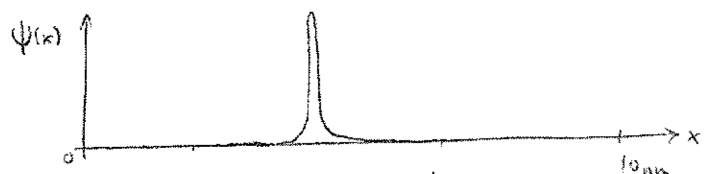
Problem 8

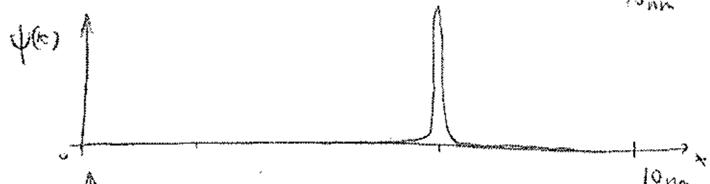


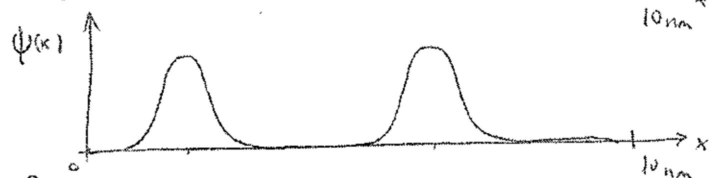
For an electron in a state represented by the wavefunction shown, a measurement of position is performed. Which of the following best represents a possible wavefunction immediately after the measurement?

A)


assume all wavefunctions are normalized.

B)


C)


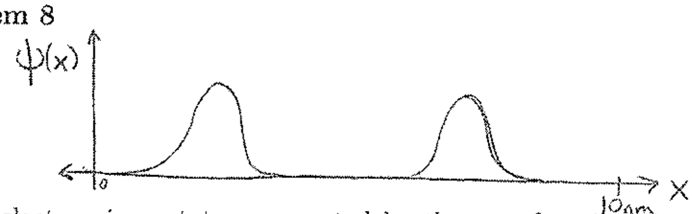
D)


Problem 9

In a double slit experiment with electrons, what happens to the interference pattern if we double the velocity of the electrons?

A) It stays the same.
B) The fringes get further apart.
C) The fringes get closer together.

Problem 8



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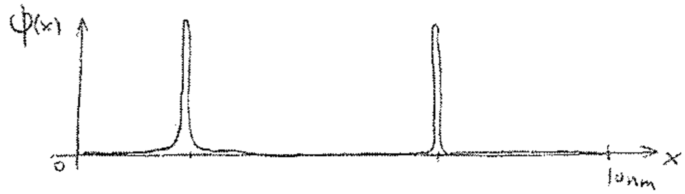

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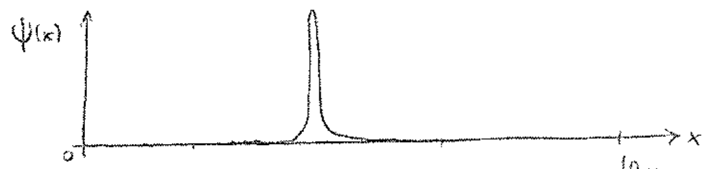
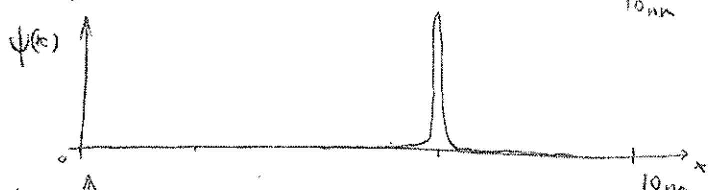
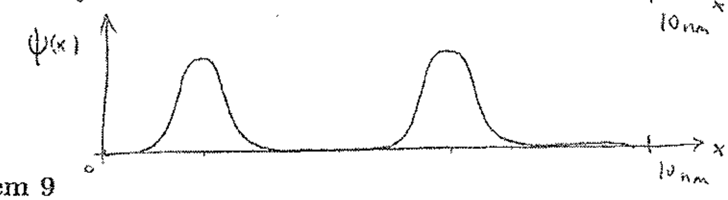
B)


C)


measure
⇒ state changes to one with definite position.

D)


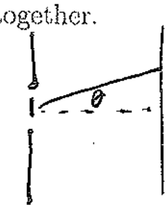
Can't be B since $|\psi|^2 = 0$ here.

Problem 9

In a double slit experiment with electrons, what happens to the interference pattern if we double the velocity of the electrons?

A) It stays the same.
B) The fringes get further apart.
C) The fringes get closer together.

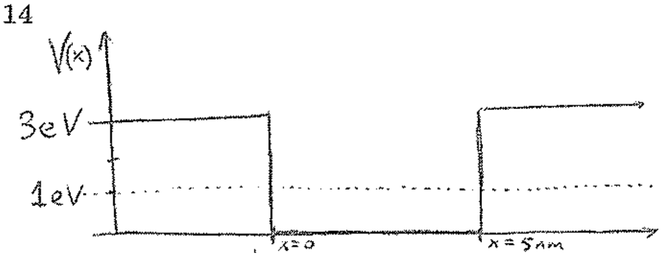
2× velocity ⇒ 2× momentum
⇒ ½ × wavelength.



bright ~~darks~~ spots at $\sin\theta = \frac{\lambda}{d} n$

smaller λ ⇒ smaller angles θ.

Problem 14



The potential energy as a function of x is shown for an electron in a short wire, where $x = 0$ and $x = 5nm$ represent the ends of the wire. If the electron is in a bound state with energy 1eV (corresponding to the dotted line shown), for which photon wavelengths would a photon be capable of liberating the electron from the wire?

A) $\lambda < hc/(1\text{eV})$
B) $\lambda < hc/(2\text{eV})$
C) $\lambda < hc/(3\text{eV})$
D) A photon of any wavelength has some probability of liberating the electron.

Problem 15

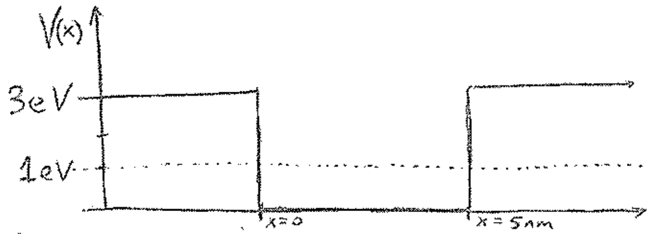
An electron in a hydrogen atom is in a state given by a superposition of the two lowest energy eigenstates

$$\psi(\vec{x}) = \frac{1}{2}\psi_1(\vec{x}) + \frac{\sqrt{3}}{2}\psi_2(\vec{x}) .$$

where ψ_1 and ψ_2 are the wavefunctions for the states with energies $E_1 = -13.6eV$ and $E_2 = -3.4eV$ respectively. If a measurement of energy is made, the most likely result is

A) -13.6eV
B) -3.4eV
C) $\frac{1}{4}$(-13.6eV) + $\frac{3}{4}$(-3.4eV)
D) either -13.6eV and -3.4eV are equally likely

Problem 14



The potential energy as a function of x is shown for an electron in a short wire, where $x = 0$ and $x = 5nm$ represent the ends of the wire. If the electron is in a bound state with energy 1eV (corresponding to the dotted line shown), for which photon wavelengths would a photon be capable of liberating the electron from the wire?

need $E > 2eV$

$\Rightarrow hf > 2eV$

$\Rightarrow \frac{hc}{\lambda} > 2eV \Rightarrow \lambda < \frac{hc}{2eV}.$

A) $\lambda < hc/(1\text{eV})$
B) $\lambda < hc/(2\text{eV})$
C) $\lambda < hc/(3\text{eV})$
D) A photon of any wavelength has some probability of liberating the electron.

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A) -13.6eV
B) -3.4eV
C) $\frac{1}{4}$(-13.6eV) + $\frac{3}{4}$(-3.4eV)
D) either -13.6eV and -3.4eV are equally likely

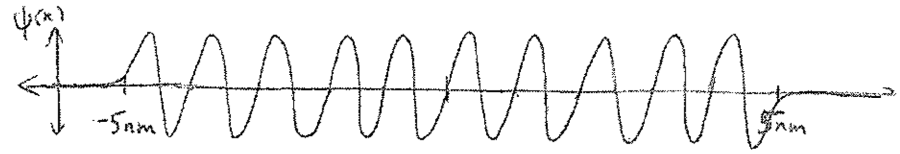
possible results:

E_1 prob. $\left(\frac{1}{2}\right)^2 = \frac{1}{4}$

E_2 prob $\left(\frac{\sqrt{3}}{2}\right)^2 = \frac{3}{4}$

most likely

Problem 18



The graph above shows the real part of a one-dimensional wavepacket for an electron traveling in a thin wire. For this electron, the uncertainty in position is closest to

A) 0.5nm
B) 5nm
C) 0
D) $\hbar$

Problem 19

For the electron in the previous problem, the momentum is approximately

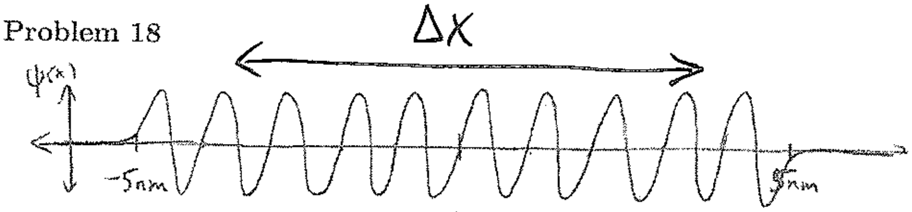
A) 6.6×10^{-25} kg m/s
B) 6.6×10^{-26} kg m/s
C) 1.3×10^{-25} kg m/s
D) 1.3×10^{-20} kg m/s

Problem 20

For the electron in the previous two problems, the minimum uncertainty in momentum is closest to

A) 10^{-24} kg m/s
B) 10^{-25} kg m/s
C) 10^{-26} kg m/s
D) $\hbar/2$

Problem 18



The graph above shows the real part of a one-dimensional wavepacket for an electron traveling in a thin wire. For this electron, the uncertainty in position is closest to

A) 0.5nm
B) 5nm
C) 0
D) $\hbar$

roughly: uncertainty ~range over which we might find electron.

Problem 19

For the electron in the previous problem, the momentum is approximately

A) 6.6×10^{-25} kg m/s
B) 6.6×10^{-26} kg m/s
C) 1.3×10^{-25} kg m/s
D) 1.3×10^{-20} kg m/s

$$p = \frac{h}{\lambda} \approx \frac{6.6 \times 10^{-34}\ \text{Js}}{1\text{nm}}$$

~~**Problem 20**~~

~~For the electron in the previous two problems, the minimum uncertainty in momentum is closest to~~

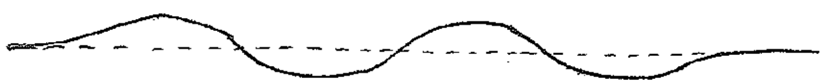
~~A) 10^{-24} kg m/s~~
~~B) 10^{-25} kg m/s~~
~~C) 10^{-26} kg m/s~~
~~D) $\hbar/2$~~

Problem 15

The wavefunction for a traveling electron is described by a wavepacket whose real part is shown above. Which of the following could be the real part of the wavefunction for an electron traveling with half the momentum?

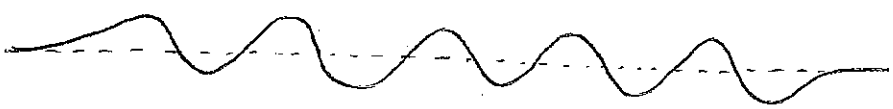
A

B



C

D



Problem 16

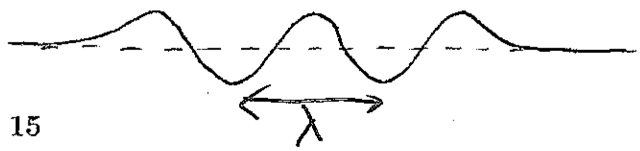
Wavepackets for traveling particles tend to spread out with time, a phenomenon known as dispersion. Which of the wavepackets below (real part shown) will spread out the fastest?

A

B

C

D



Problem 15

The wavefunction for a traveling electron is described by a wavepacket whose real part is shown above. Which of the following could be the real part of the wavefunction for an electron traveling with half the momentum?

$\boxed{p = \frac{h}{\lambda}}$

half p
⇒ twice λ

A

B

C

D

Problem 16

Wavepackets for traveling particles tend to spread out with time, a phenomenon known as dispersion. Which of the wavepackets below (real part shown) will spread out the fastest?

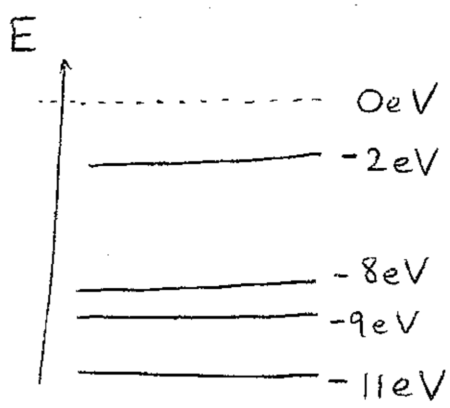
shortest wavepacket
⇒ largest range of momenta / wavelengths in superposition
⇒ fastest spreading.

A

B

C

D



Problem 17

The diagram above shows the allowed energy levels for an electron in some molecule, relative to the energy $E = 0eV$ it would take for the electron to escape. If the electron is in its ground state, and absorbs a photon with energy $14eV$, the final kinetic energy of the electron will be

A) 14eV

B) 12eV

only one of these is right...

C) 3eV

D) 25eV

E) The electron cannot absorb a photon with energy $14eV$.

Problem 18

For a gas of the molecules in the previous question, how many spectral lines will be present in the emission spectrum?

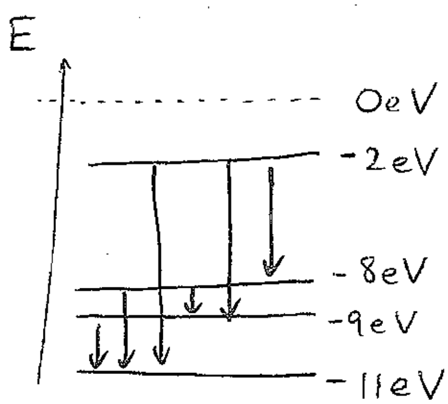
A) 3

B) 4

C) 5

D) 6

E) 10



Problem 17

The diagram above shows the allowed energy levels for an electron in some molecule, relative to the energy $E = 0eV$ it would take for the electron to escape. If the electron is in its ground state, and absorbs a photon with energy $14eV$, the final kinetic energy of the electron will be

A) 14eV

B) 12eV

C) 3eV

D) 25eV

E) The electron cannot absorb a photon with energy $14eV$.

Original electron energy : −11eV

Photon adds 14eV, so 3eV left over

* Any energy $E > 0$ possible since these correspond to electrons outside an atom.

Problem 18

For a gas of the molecules in the previous question, how many spectral lines will be present in the emission spectrum?

A) 3

B) 4

C) 5

D) 6

E) 10

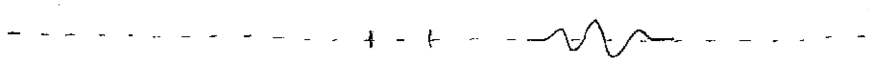
see figure. above

Problem 19

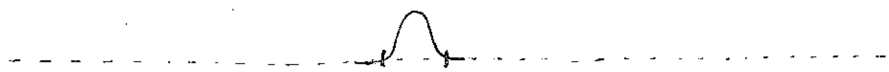
Suppose we have a short air gap between two wires. If we send an electron towards the air gap with an energy less than the work function of the metal, which of the following could be a wavefunction that results?

amount of energy that it takes to get the electron out of the metal.

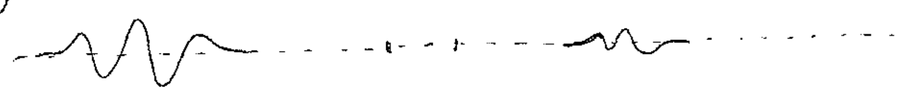
(A)



(B)



(C)

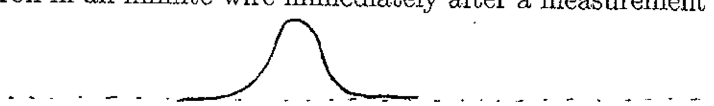


(D) Any of the above (E) None of the above

Problem 20

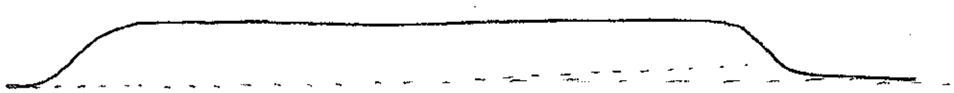
Which of the following is the most likely wavefunction (real part) for an electron in an infinite wire immediately after a measurement of momentum?

(A)

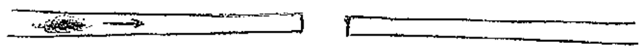


(B)

(C)

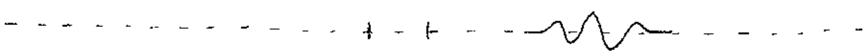


(D)

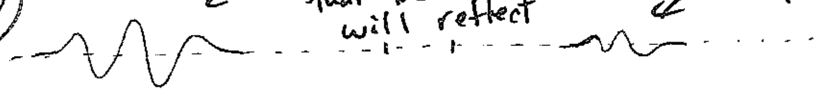


Problem 19

Suppose we have a short air gap between two wires. If we send an electron towards the air gap with an energy less than the work function of the metal, which of the following could be a wavefunction that results?

(A) 

(B) 

(C) 

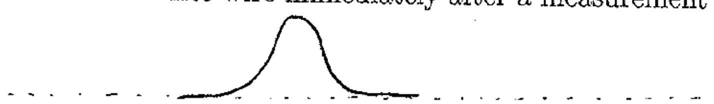
Some probability that the electron will reflect

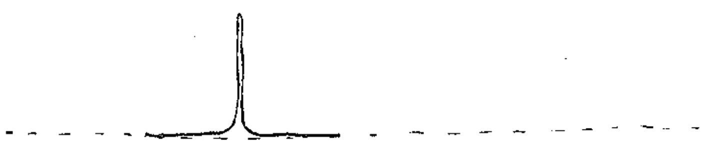
Some probability that the electron will tunnel into the other wire.

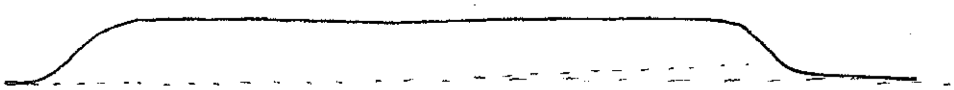
(D) Any of the above (E) None of the above

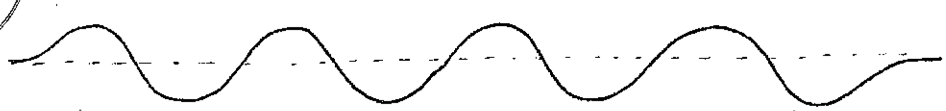
Problem 20

Which of the following is the most likely wavefunction (real part) for an electron in an infinite wire immediately after a measurement of momentum?

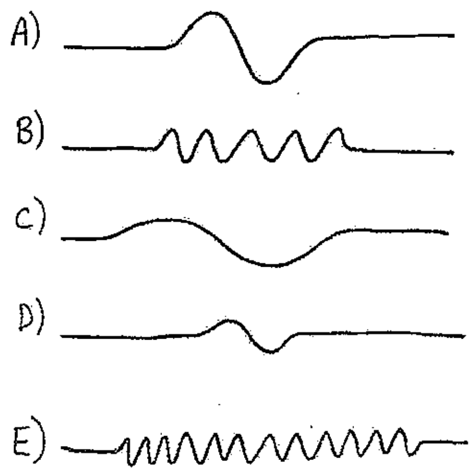
(A) 

(B) 

(C) 

(D) 

Measure $p \rightarrow$ get state with fairly definite momentum.



The five functions shown above represent the real part of the wavefunctions for traveling electrons.

Question 1: Which wavefunction describes the particle with the largest momentum?

A) A B) B C) C D) D E) E

Question 2: Which wavefunction describes the particle with the largest uncertainty in momentum?

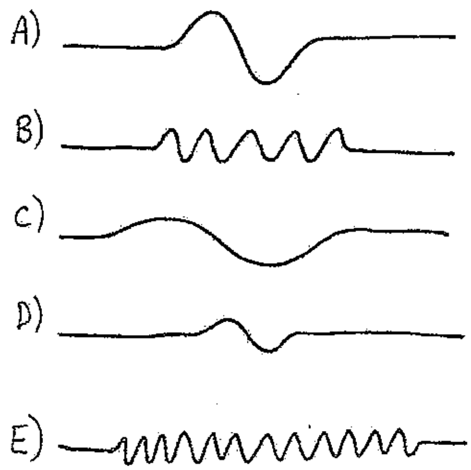
A) A B) B C) C D) D E) E

Question 3: Which wavefunction describes the particle with the largest uncertainty in position?

A) A B) B C) C D) D E) E

Question 4: A double slit experiment is performed with electrons and an interference pattern is observed. A beam of *neutrons* (larger mass particles) with the same momentum as the electrons is now sent through the same slits. Compared to the pattern observed for electrons, the neutron interference pattern has "bright" spots which are

A) closer together
B) further apart
C) at the same locations
D) in a completely different pattern.



The five functions shown above represent the real part of the wavefunctions for traveling electrons.

Question 1: Which wavefunction describes the particle with the largest momentum?

A) A B) B C) C D) D E) E

largest p
⇒ smallest λ

Question 2: Which wavefunction describes the particle with the largest uncertainty in momentum?

A) A B) B C) C D) D E) E

shortest wave packet
→ largest range of λ needed to make wave
→ largest uncertainty in p

Question 3: Which wavefunction describes the particle with the largest uncertainty in position?

A) A B) B C) C D) D E) E

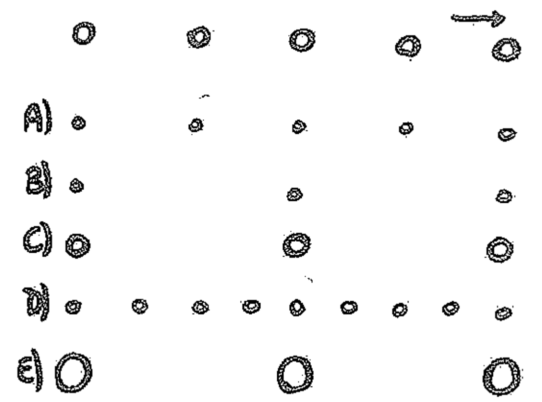
uncertainty in position
= how spread out is wavefunction.

Question 4: A double slit experiment is performed with electrons and an interference pattern is observed. A beam of *neutrons* (larger mass particles) with the same momentum as the electrons is now sent through the same slits. Compared to the pattern observed for electrons, the neutron interference pattern has "bright" spots which are

A) closer together
B) further apart
C) at the same locations
D) in a completely different pattern.

Same momentum
⇒ same wavelength
⇒ same pattern.

Question 5: The first picture below represents the photons in a beam of light with some wavelength and intensity. If size represents photon energy in the picture, which of the remaining pictures best represents a beam of light with half the frequency and half the intensity?



Question 6: A new kind of particle is produced in a particle accelerator. In the experiment the new particles are always produced traveling at $v = 0.8c$, and are observed to decay after they have traveled a distance of 3 meters on average. We can conclude that the half life of the new particle is closest to

A) 0.6×10^{-8} seconds
B) 0.8×10^{-8} seconds
C) 1.0×10^{-8} seconds
D) 1.25×10^{-8} seconds
E) 1.67×10^{-8} seconds

Question 7: In a photoelectric effect experiment, no photons are observed when a beam of light illuminates the metal. Which of the following changes will likely result in photoelectrons being ejected?

A) Doubling the intensity
B) Doubling the wavelength
C) Focusing the beam down to a smaller area
D) All of the above
E) None of the above

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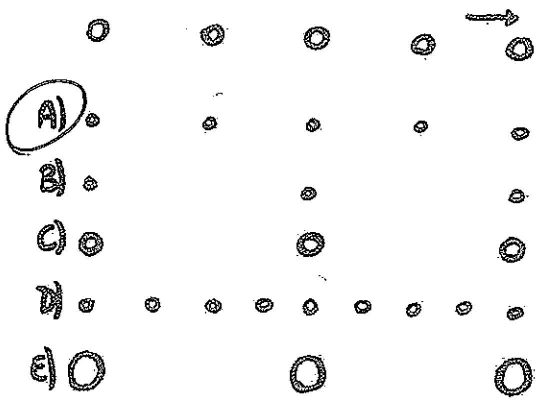

$\frac{1}{2}$ freq. $\Rightarrow$ $\frac{1}{2}$ energy per photon.

$\therefore$ will have $\frac{1}{2}$ intensity with same rate of photons

Question 6: A new kind of particle is produced in a particle accelerator. In the experiment the new particles are always produced traveling at v = 0.8c, and are observed to decay after they have traveled a distance of 3 meters on average. We can conclude that the half life of the new particle is closest to

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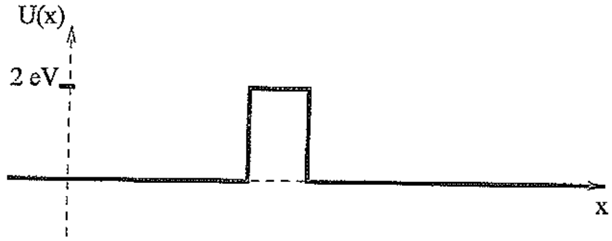
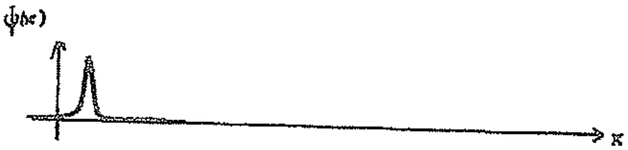
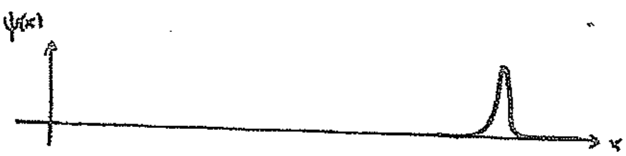
B) Doubling the wavelength
C) Focusing the beam down to a smaller area
D) All of the above
E) None of the above

need to decrease wavelength.



Question 21: An electron with energy 1eV is initially in a state described by a wavepacket traveling in from the left in a region for which the electron's potential energy is shown above. After some time, the position of the electron is measured. Which of the pictures below could be a possible wavefunction for the electron just after this measurement? (choose the best answer)

A) 

B) 

c) 

D) Both A and B are possible

E) Any of A, B, or C are possible

Question 22: The first picture below represents the probability density for an electron in an energy eigenstate. Which of the options below best represents the probability density at some later time?

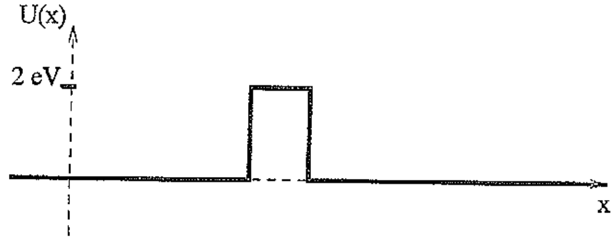
A 

B 

C 

D) Either A or B

E) Any of these is possible, depending on the potential U(x)



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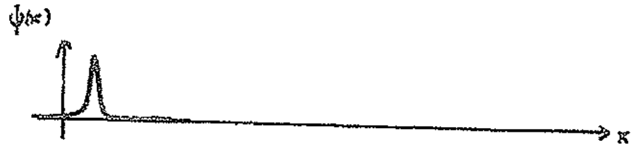
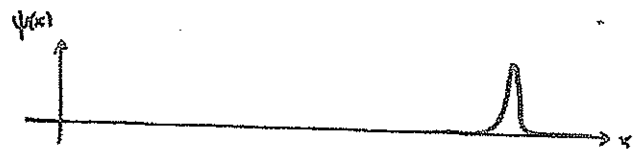
A) 

B) 

c) 

after measurement: will have definite position ∴ B or A. both possible since we can have tunelling.

D) Both A and B are possible

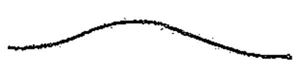
E) Any of A, B, or C are possible

Question 22: The first picture below represents the probability density for an electron in an energy eigenstate. Which of the options below best represents the probability density at some later time?

Probability density constant in time for an energy eigenstate.

A 

B 

C 

D) Either A or B

E) Any of these is possible, depending on the potential U(x)

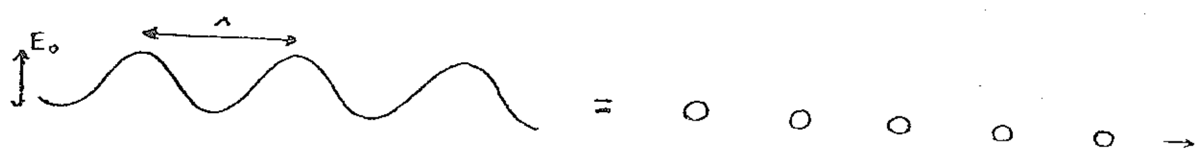
① ~~A massless particle has energy 13 MeV. What is its velocity?~~

---

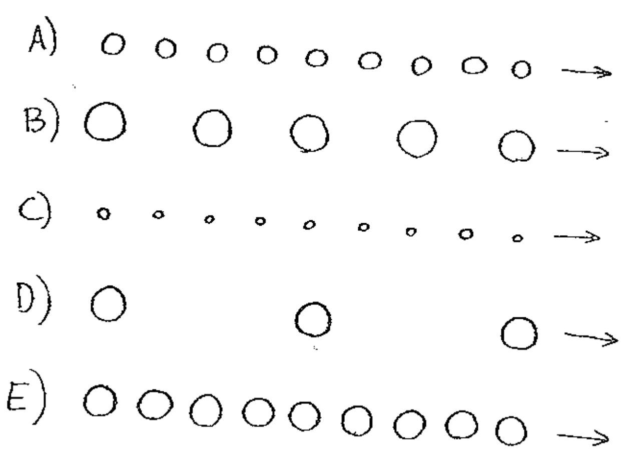
② 

A metal surface is illuminated with light whose wavelength is short enough to produce photoelectrons. If we now switch to light with half the wavelength but keep the total power of the beam the same, what happens to the maximum kinetic energy of the electrons?

a) It stays the same
b) It doubles (increases by 100%)
c) It increases, but by less than 100%
d) It is cut in half
e) It increases by more than 100%

④ 

The picture on the right above represents the photons making up an electromagnetic wave. Which of the pictures below best represents the photons making up a wave with the same amplitude and half the wavelength?



NOTE: size represents energy in the pictures to the right

(1) ~~A massless particle has energy 13 MeV. What is its velocity?~~

~~All massless particles must have velocity c to have nonzero energy~~

~~$\boxed{\text{Answer: c}}$~~

---

(2)

A metal surface is illuminated with light whose wavelength is short enough to produce photoelectrons. If we now switch to light with half the wavelength but keep the total power of the beam the same, what happens to the maximum kinetic energy of the electrons?

initially:

$$E_k^{max} = \frac{hc}{\lambda} - W$$

after:

$$\tilde{E}_k^{max} = \frac{2hc}{\lambda} - W$$

$$\frac{\tilde{E}_k^{max}}{E_k^{max}} = \frac{2 - \frac{W\lambda}{hc}}{1 - \frac{W\lambda}{hc}} > 2$$

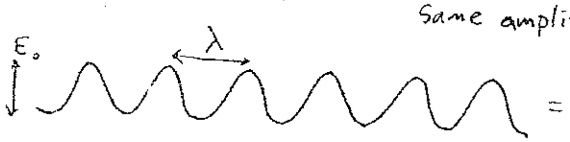
a) It stays the same
b) It doubles (increases by 100%)
c) It increases, but by less than 100%
d) It is cut in half
e) It increases by more than 100%

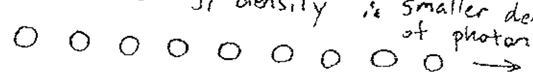
---

(4)

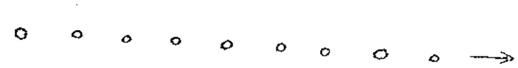
The picture on the right above represents the photons making up an electromagnetic wave. Which of the pictures below best represents the photons making up a wave with the same amplitude and half the wavelength?

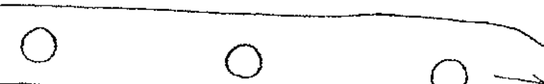
smaller wavelength = greater energy per photon
Same amplitude = same energy density ∴ smaller density of photons



A) 

B) 

C) 

D) 

E) 

NOTE: size represents energy in the pictures to the right