Chapter 27 MATTER WAVES

Throughout this course we have been developing models for physical phenomena and investigating the aspects of these models which agreed with observations and which did not. We found that light sometimes acts like a wave and other times acts like a particle. Over the past few chapters we have also been pecking away at the features of a physical model which accounts for the fact that this dual behavior is not restricted just to light. In fact, <u>all matter</u> exhibits qualities that are sometimes wave-like and at other times particle-like. Accordingly, this chapter introduces the famous hypothesis of de Broglie (de-BROI-lee) which expresses this duality in mathematical terms.

Using the de Broglie relationship, we discover that the wave nature of matter can be neglected in may circumstances related to everyday life. The motion of the planets, the working of an electric motor, and the structural strength of a building all can be described without consideration of "matter waves". However, when attempting to understand phenomena which relate directly to the structure and properties of atoms, molecules, nuclei, or their constituent particles, the wave nature of matter becomes all-important. In this chapter, we will develop a model for the atom, using a description that is correct in that it represents the state of man's understanding of the atom at the present time.

PERFORMANCE OBJECTIVES

after completing this chapter, you should be able to:

1. mathematically state de Broglie's proposal that particles have a wavelength and be able to calculate its wavelength given the mass and relative velocity of the particle.

2. verbally explain when and why the wave nature of matter is of significant importance for a given situation.

3. calculate the minimum energy a particle needs to exist within a given region.

4. use $E=mc^2$ to calculate the energy of the photons that are produced when anti-matter annihilates matter.

5. summarize the standing wave theory for the hydrogen atom.

6. develop an awareness that the wave equations indicate only the probability of where a particle is located and what it will do, and that we are unable to know anything more than the probability of what will happen.

1. Film: "Matter Waves" 28 min (Film notes provided.)

2. Read: Section 27-1 A New Kinematics For Particles? page 549
   Section 27-2 Evidence for Matter Waves

   a. de Broglie proposed that if $E = pc = \frac{hc}{\lambda}$, then maybe λ = _____ = _____.

   b. Since $E = mc^2$, the extrapolation is from m·c to _______.

   c. From (a) one can conclude that a change in momentum will cause a change in ____________.

   d. Since $\Delta x = L\lambda/d$, a change in wavelength will cause a change in ______________________________________.

   e. What evidence supports this theory?

   f. If a change in momentum will cause a change in the wavelength, so too will a change in _______________.

   g. Given an accelerating potential 'V' through which a charge "q" is accelerated from rest, one finds its wavelength from $\lambda = h/mv$ by:

      (1) Since $E_K = 1/2\ mv^2$, v = ______________.

      (2) Knowing that $V = E/q$ and that all the work done goes into a change of kinetic energy, v = _______________.

      (3) Thus: λ = ______________.

3. What is the wavelength of the following?

   a. You when you are moving at a speed of 60 mi/hr (26.9 m/sec).

   b. An electron moving at the same speed.

4. Problems Page 554: #1 #2
   Page 564: #14 #15 #16

5. Read: Section 27-3 Standing Waves page 554

   a. How will we explain the presence of definite internal energy levels in atoms and the simple numerical relations they sometime have?

      (1) What is known about the stability of the energy of an electron within an atom?

      (2) What is known about the energy states of electrons within the atom?

      (3) What is known about the matter wave for each energy level?

      (4) Thus what must we look for as a model to explain energy levels?

      (5) Does anything you have encountered before fit the situation?

b. Using the variable speed rotator and oscillator attachment, make standing waves in the string. You can vary the pattern form 1 to 2 to 3 or more loops by increasing the tension on the string.

(1) How many wavelength(s) long is each loop?

(2) Can you feel the stability of the standing wave pattern?

6. Problems: Page 556 #6 #7

7. Read: Section 27-4 A Particle in a "Box" page 556

Assume that an electron is trapped between two walls on opposite sides of a box, moving with speed 'v' and undergoing an elastic collision with the walls.

a. The electron traveling with velocity 'v' has a wavelength: λ = _______________.

b. Knowing that $E = 1/2\ mv^2$ and $E = p^2/2m$ and information from (a), then E = _______________.

c. If 'd' represents the distance between walls, then the minimum wavelength is: λ = _______________.

d. Thus: E = _______________.

e. Other possible wavelengths are 2d/2, 2d/3. 2d/4, . . . Thus λ_n = _________.

f. Therefore: E_n = _______________.

g. Changing from an electron trapped between two walls to an electron trapped within a box alter the equation in (f) by: E = _______________.

h. The numbers n_x, n_y, n_z, are called _____________ numbers.

i. The ground state for any atom E_o = _______________.

8. Problems: Page 558 #8 #9 #10
Page 565 #21

9. Read: Section 27-5 The Standing Wave Model of the Hydrogen Atom p 558

a. To calculate the internal energy E_T of an atom, one proceeds as follows:

(1) The total energy equals the sum of the kinetic and potential energy. Thus, E_T = _________ + _________.

(2) Knowing that $E_{K_2} = 1/2\ mv^2$ and $U_e = -\ kqQ/r$,

E_T = _______________ + _______________.

(3) Knowing that $mv^2/r = kqQ/r^2$, one finds that $1/2\ mv^2$ = _________.

(4) Thus: E_T = _______________.

b. To solve for 'v' we must use both the classical and quantum ideas as follows:

(1) The electron in an atom is under a Coulomb force of the nucleus where: F = _______________.

(2) From our classical beginning which identified the electron as being in a circular orbit at constant distance 'r' form the nucleus. Knowing that $F = mv^2/r$, then mv^2 = _______________. (If 'r' and 'v' remain constant, then the momentum will remain constant.)

(3) Our quantum understanding says that = h/mv. If the momentum remains constant, then the _______________ remains constant.

(4) To locate the electron we assume the matter wave of the electron exists within a narrow channel with radius 'r' and that the circumference must be a whole number of wavelengths. Thus $n\lambda$ = ____________.

(5) Equating the equations in (3) and (4), mv = _______________.

(6) Solving for 'v' using the classical theory equation from (2) and the quantum theory idea equation from (5), one gets v = _______________.

c. Finally solving for the total internal energy from [a(4) and b(6)], one gets E_T = _______________.

d. For the hydrogen atom, both Q and q are 1 elementary charge. Thus E_T = ____________________Joules or ____________________ eV.

e. How does the value in (d) compare to that determined in chapter 26?

10. Experiment: The Spectrum of Hydrogen and Planck's Constant #43

11. Problems: Page 561 #12 #13
Page 565 #24 #25

12 Read: Section 27-6 Epilogue page 561

Film: "Matter Waves" 28 min (Film notes provided.) *New Mech Univ Wave & Particle*

2. Read: Section 27-1 A New Kinematics For Particles? page 549
   Section 27-2 Evidence for Matter Waves

a. de Broglie proposed that if $E = pc = \frac{hc}{\lambda}$, then maybe λ = *$\frac{h}{p}$* = *$\frac{h}{mv}$*.

b. Since $E = mc^2$, the extrapolation is from m·c to *mv*.

c. From (a) one can conclude that a change in momentum will cause a change in *wavelength*.

d. Since $\Delta x = L\lambda/d$, a change in wavelength will cause a change in *spacing between dark & light bars*.

e. What evidence supports this theory? *- film Matter Wave*

f. If a change in momentum will cause a change in the wavelength, so too will a change in *energy*.

g. Given an accelerating potential 'V' through which a charge "q" is accelerated from rest, one finds its wavelength from $\lambda = h/mv$ by:

(1) Since $E_K = 1/2\ mv^2$, v = *$\sqrt{\frac{2E_K}{m}}$*.

(2) Knowing that V = E/q and that all the work done goes into a change of kinetic energy, v = *$\sqrt{2Vq/m}$*.

(3) Thus: λ = *$\frac{h}{m}\sqrt{\frac{m}{2Vq}}$*. *$\lambda = \frac{h}{mv} = \frac{h}{m}\sqrt{\frac{m}{2Vq}}$*

3. What is the wavelength of the following?

a. You when you are moving at a speed of 60 mi/hr (26.9 m/sec). *2.47×10^{-37} m*

b. An electron moving at the same speed. *2.71×10^{-5} m*

4. Problems Page 554: #1 #2
   Page 564: #14 #15 #16

5. Read: Section 27-3 Standing Waves page 554

a. How will we explain the presence of definite internal energy levels in atoms and the simple numerical relations they sometime have?

(1) What is known about the stability of the energy of an electron within an atom? *Very stable*

(2) What is known about the energy states of electrons within the atom? *are definite & separate*

(3) What is known about the matter wave for each energy level? *need separate λ's as energy different*

(4) Thus what must we look for as a model to explain energy levels? *several distinct wave patterns*

(5) Does anything you have encountered before fit the situation? *How about a Standing Wave*

Erion

b. Using the variable speed rotator and oscillator attachment, make standing waves in the string. You can vary the pattern form 1 to 2 t... or more loops by increasing the tension on the string.

(1) How many wavelength(s) long is each loop? $1/2 \lambda$

(2) Can you feel the stability of the standing wave pattern?

6. Problems: Page 556 #6 #7

7. Read: Section 27-4 A Particle in a "Box" page 556

Assume that an electron is trapped between two walls on opposite sides of a box, moving with speed 'v' and undergoing an elastic collision with the walls. Components of p in both x & -x as 2 waves superimpose ∴ $p_T = \emptyset$

a. The electron traveling with velocity 'v' has a wavelength: λ = h/mv.

b. Knowing that $E = 1/2\ mv^2$ and $E = p^2/2m$ and information from (a), then E = $h^2/2m\lambda^2$.

Erion

c. If 'd' represents the distance between walls, then the minimum (maximum) wavelength is: λ = $2d$.

d. Thus: E = $h^2/8md^2$.

e. Other possible wavelengths are 2d/2, 2d/3. 2d/4, . . . Thus λ_n = $2d/n$.

f. Therefore: E_n = $h^2n^2/8md^2$.

g. Changing from an electron trapped between two walls to an electron trapped within a box alter the equation in (f) by: E = $(n_x^2 + n_y^2 + n_z^2)\frac{h^2}{8md^2}$.

h. The numbers n_x, n_y, n_z, are called quantum numbers.
∴ Energy levels depend on mass of particle, size box

i. The ground state for any atom E_o = $3h^2/8md^2$. as $(1+1+1)$

8. Problems: Page 558 #8 #9 #10
Page 565 #21

9. Read: Section 27-5 The Standing Wave Model of the Hydrogen Atom p 558

a. To calculate the internal energy E_T of an atom, one proceeds as follows:

(1) The total energy equals the sum of the kinetic and potential energy. Thus, E_T = E_K + U.

(2) Knowing that $E_{K_2} = 1/2\ mv^2$ and $U_e = - kqQ/r$,
E_T = $\frac{1}{2}mv^2$ + $(-\frac{kqQ}{r})$.

(3) Knowing that $mv^2/r = kqQ/r^2$, one finds that $1/2\ mv^2$ = $\frac{1}{2}\frac{kQq}{r}$.

(4) Thus: E_T = $-\frac{1}{2}mv^2$.

Erica

b. To solve for 'v' we must use both the classical and quantum ideas as follows:

(1) The electron in an atom is under a Coulomb force of the nucleus where: F = Kqq/r^2.

(2) From our classical beginning which identified the electron as being in a circular orbit at constant distance 'r' form the nucleus. Knowing that $F = mv^2/r$, then mv^2 = $Kq Q/r$. (If 'r' and 'v' remain constant, then the momentum will remain constant.)

(3) Our quantum understanding says that $\lambda = h/mv$. If the momentum remains constant, then the wavelength remains constant.

$\lambda = \frac{h}{mv}$ $\frac{2\pi r}{n}$

(4) To locate the electron we assume the matter wave of the electron exists within a narrow channel with radius 'r' and that the circumference must be a whole number of wavelengths.
Thus $n\lambda$ = $2\pi r$.

(5) Equating the equations in (3) and (4), mv = $\frac{nh}{2\pi r}$.

(6) Solving for 'v' using the classical theory equation from (2) and the quantum theory idea equation from (5), one gets v = $\frac{2\pi KqQ}{nh}$.

c. Finally solving for the total internal energy from [a(4) and b(6)], one gets E_T = $-\frac{1}{2} m \left(\frac{2KqQ}{h}\right)^2 \frac{1}{n^2}$.

d. For the hydrogen atom, both Q and q are 1 elementary charge.
Thus E_T = $-2.17 \times 10^{-18}/n^2$ Joules or $-13.6\,eV$ eV.

e. How does the value in (d) compare to that determined in chapter 26?

10. Experiment: The Spectrum of Hydrogen and Planck's Constant #43

11. Problems: Page 561 #12 #13
Page 565 #24 #25

12 Read: Section 27-6 Epilogue page 561

#2 $v = \frac{KqQ}{r\,mv}$

#5 $mv = \frac{nh}{2\pi r}$

#6 $v = \frac{KqQ\,2\pi r}{r\,nh}$

$v = \frac{2\pi K\,qQ}{nh}$

$E_T = -\frac{1}{2}mv^2$

$= -\frac{1}{2}m\left(\frac{2\pi KqQ}{nh}\right)^2$

$= -\frac{1}{2}m\frac{4\pi^2K^2q^2Q^2}{h^2}\frac{1}{n^2}$

$= \frac{2\pi^2K^2q^2Q^2m}{h^2}\cdot\frac{1}{n^2}$

Chapter 27 ANSWERS

2. (a) $h/p = h/mv$ (b) mv (c) wavelength
   (d) the spacing between bright and dark bars of double slit interference pattern
   (e) the film Matter Waves had the answer (f) energy

   (g) (1) $\sqrt{2E_K/m}$ (2) $\sqrt{2Vq/m}$ (3) $h/m \cdot \sqrt{m/2Vq}$

3. (a) 2.47×10^{-37} m (b) 2.71×10^{-5} m

4. (1) 0.073 nm
   (2) 2λ
   (14) 10^4 eV
   (15) reduces Δx tenfold
   (16)(a) 0.36 m (b) S.A.B.

5. (a)(1) very stable
   (2) are definite and separate
   (3) need separate wavelengths as energy is different
   (4) several distinct wave patterns
   (5) How about a standing wave?
   (b)(1) 1/2 wavelength
   (2) I hope so

6. (6)(a) 0.125 Hz, 0.25 Hz, 0.375 Hz, . . . (b) no
   (7) 1/2 wavelength, 1 wavelength, 3/2 wavelength, 2 wavelength

7. (a) h/mv (b) $h^2/2m\lambda^2$ (c) 2d (d) $h^2/8md^2$ (e) 2d/n

   (f) $h^2 n^2/8md^2$ (g) $[n_x^2 + n_y^2 + n_z^2]\, h^2/8md^2$ (h) quantum

   (i) $3h^2/8md^2$

8. (8) No
   (9) 10^{-17} Joule
   (10) 9.93×10^{-13} Joules
   (21)(a) 5.5×10^6 eV (b) It must increase

9. (a)(1) $E_K + U_e$ (2) $1/2\ mv^2 + (-kqQ/r)$ (3) $1/2\ kqQ/r$ (4) $-1/2\ mv^2$

   (b)(1) kqQ/r^2 (2) kqQ/r (3) wavelength (4) $2\pi r$ (5) $nh/2\pi r$

   (6) $2\pi kqQ/r^2$

   (c) $-1/2\ m\left(\frac{2kqQ}{h}\right)^2 \cdot \frac{1}{n^2}$ (d) $-2.17 \times 10^{-18}/n^2$ or $-13.6/n^2$

11. (12) $E_1 = -13.6$ eV, $E_2 = -3.4$ eV, $E_3 = -1.5$ eV, $E_4 = 0.85$ eV
    (13) Integral number of whole wavelengths
    (24) 3/4
    (25) S.A.B.

Chapter 27 NOTES

<u>Particles and Photons</u> - We have seen that some of the properties of particles are the same as some of the properties of light. The similarity is in some cases remarkable. It is difficult to show the particle properties of electromagnetic radiation, and difficult to show the wave-nature of particles, at least with ordinary laboratory apparatus. But let us be careful to make a fair comparison: between photons and particles of the <u>same wavelength</u>. For the electrons which made the interference pattern in Figure 27-5, the wavelength is 8.6×10^{-12} m. A photon with that wavelength has an energy of 20,000 electron volts, and X-rays with this energy exhibit quite marked particle like properties in atomic collisions. But the photon and the electron, each with wavelength equal to 8.6×10^{-12} m, are distinguishable. For one thing, an electric field will deflect the electron, but not the photon. The electron has a charge, the photon is electrically neutral. They are different. So let us compare photons and <u>neutrons</u> . . . We can go on in this way, comparing the behavior of photons with that of all the other particles we know about. There will always be some experiment which shows a difference between them. A photon is one kind of entity; we can call it a particle, provided we do not take that word in its classical sense. There are many other kinds of particles whose properties have been ascertained by experiments, and they all differ in some respect, although sometimes the differences are very small and hard to detect. One marked way in which photons differ from all other particles is in the ease with which the less energetic ones can be created. Compare a light bulb, which is creating many photons with wavelengths in the visible region, with an electrical circuit. In the circuit, passage of electrons is observed. You can never observe effects unless you make a continuous circuit for current to <u>flow</u> around. Electrons cannot be created at one end of a wire and destroyed at the other, producing a current. Their number stays constant. On the basis of what we have seen in the lab, this then is a very marked difference between photons and electrons. The other particles we have met - neutrons, protons, helium atoms - share the electron's property of being conserved in ordinary situations.

It is in fact possible to create electrons, neutrons, protons, etc. Readers of popular science magazines may have encountered antimatter; antielectrons (called positrons), antiprotons, antineutrons. It is not possible to create a single electron, for example, but a pair consisting of an electron and a positron can be created, provided the right conditions exist. A positron is a quite different particle from an electron - it has the opposite electric charge. More important, on meeting any other electron, both of the particles disappear, leaving behind energy in the form of photons.

To understand the situation one needs Einstein's theory of relativity, but the facts are as follows. For the creation of a pair, an amount of energy equal to their combined mass times the square of the velocity of light is needed. even for such light particles as electrons, an electron-positron pair requires an energy of 10^6 electron volts. So it is not <u>easy</u> to create particles. On the other hand, photons can be created <u>singly</u>, and the creation of a photon with wavelength in the visible region requires only about two electron volts of energy. With the right experimental arrangement, such photons are quite easily created; a light bulb does quite well. So in the distinguishing feature mentioned in the text, the emphasis is on the <u>ease</u> with which photons can be created. The antiparticles, by the way, are not only hard to create, they are very easy to destroy. That is why one does not encounter them in ordinary situations. The particles with which they annihilate are present in general abundance in ordinary matter.

2. SECTION 27-1

de BROGLIE : IF $E = pc = hc/\lambda$ MAYBE $\lambda = h/p = h/mv$

REALLY SAYING $m \cdot c \cong m \cdot v$

$\Delta \vec{p} \Rightarrow \Delta \lambda$ $\quad (\Delta x = \frac{L\lambda}{d})$

FILM : "MATTER WAVES" SHOWS THIS

$\lambda = \frac{h}{mv}$: $E_K = \frac{p^2}{2m} \Rightarrow p = \sqrt{2mE_K}$: $E_K = Vq$

$$\lambda = \frac{h}{\sqrt{2mVq}} = \frac{h}{m}\sqrt{\frac{m}{2Vq}}$$

3. YOUR MASS = 10^2 Kg YOUR VELOCITY = 60 mi/hr = 26.9 M/sec

YOUR λ = ____________

MASS $_{-1}e^0$ = 9.1×10^{-31} Kg VELOCITY $_{-1}e^0$ = 26.9 M/sec

λ OF $_{-1}e^0$ = ____________

5. MASS CAR = 10^3 Kg v_{CAR} = 1 M/sec

λ = ____________ IMPORTANT ??

MASS BASEBALL = 1-Kg v = 80 mi/hr = 35.76 M/sec

λ = ____________

6. THEORY : PARTICLE HAS WAVELENGHT

IF λ SMALL COMPARED TO SIGNIFICENT DIMENSIONS OF PROBLEM THEN RESULTS (BEHAVIOR) IS PREDICTED BY CLASSICAL MECHANICS

8. $_{-1}e^0$ HAS E_K = 90 ev: λ = ____________

9. DIAMETER OF ATOM = 10^{-10} M ($-1e^0$ INSIDE)

ENERGY OF $-1e^0$ = ______________

$$E = \frac{1}{2}mv^2 = \frac{p^2}{2m} \; : \; \lambda = \frac{h}{mv} \quad \therefore \; E = \frac{h^2}{2m\lambda^2}$$

$-1e^0$ INSIDE NUCLEWS $d = 10^{-14}$ M

E = ______________

NEUTRON INSIDE NUCLEUS $m = 1.7 \times 10^{-27}$ Kg

$d = 10^{-14}$ M E = ______________

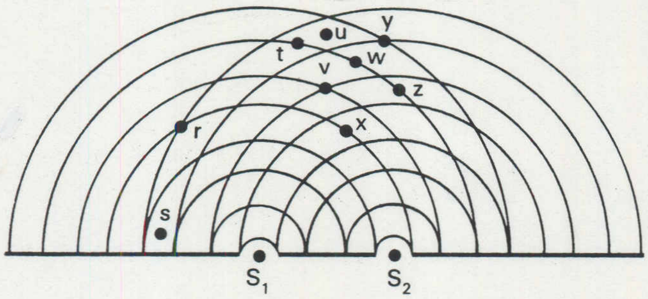
STUDENT NAME ______________________________

TEST 6

PSSC PHYSICS

FOR QUESTIONS 1-3:

The diagram shows ripples from sources S_1 and S_2 in a ripple tank. Various points *r* through *z* are marked on the diagram. The lines represent wave crests.



1. Which of the lettered points listed below is one-half wavelength farther from one source than from the other?

(A) *r* (B) *u* (C) *x* (D) *y* (E) *z*

2. Which of the lettered points listed below represents a double crest which is one wavelength farther from one source than from the other?

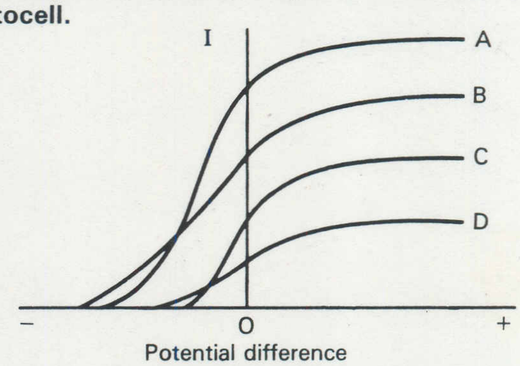
(A) *u* (B) *v* (C) *w* (D) *y* (E) *z*

3. Which one of the pairs of lettered points listed below lies on a single nodal line?

(A) *w* and *x*
(B) *x* and *z*
(C) *u* and *v*
(D) *v* and *x*
(E) *r* and *v*

FOR QUESTIONS 4 AND 5:

The graph shows the results of an experiment involving the photoelectric effect. The graph shows the currents observed in the photocell circuit as a function of the potential difference between the plates of the photocell when light beams A, B, C, and D, having four different wavelengths, were each directed, in turn, at the photocell.



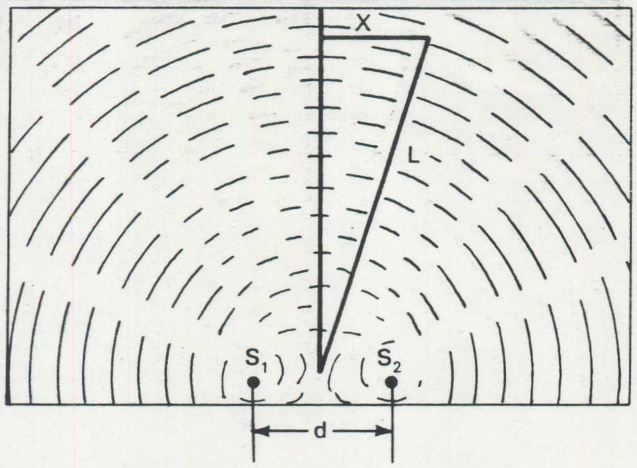
4. Which of the beams had the longest wavelength?

(A) A
(B) B
(C) C
(D) D
(E) They all had the same wavelength.

5. Which of the beams ejected photoelectrons having the greatest kinetic energy?

(A) A
(B) B
(C) C
(D) D
(E) They all ejected photoelectrons having the same momentum.

6. A student observes the wave pattern shown below as he experiments with periodic waves in a ripple tank. He draws the straight lines shown superimposed on the figure. Which of the expressions below gives the correct wavelength?



(A) x/L
(B) dx/L
(C) $2dx/L$
(D) $2x/3L$
(E) $2dx/3L$

FOR QUESTIONS 7 AND 8:

The same student now wishes to continue studying patterns similar to that shown in the figure in Question 6, but under different conditions; he considers

I. increasing the frequency of the waves.
II. increasing the separation of the sources.
III. introducing a phase delay in S_2.

7. Which of the changes above will result in a larger number of nodal lines?

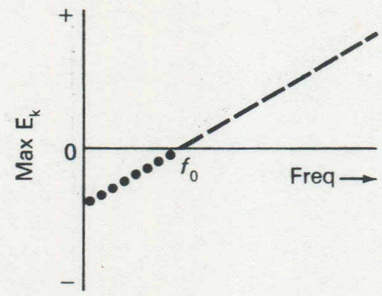
(A) I and II only
(B) I only
(C) II only
(D) III only
(E) I, II and III

8. Which of the changes above will result only in a shift of the nodal lines?

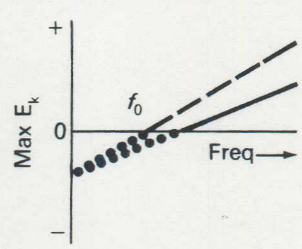
(A) I only
(B) II only
(C) III only
(D) I and II only
(E) I, II and III

FOR QUESTIONS 9 AND 10:

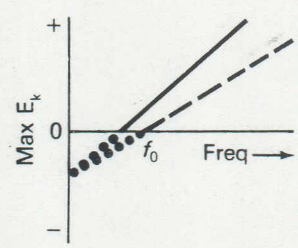
Electromagnetic energy of a fixed intensity but of varying frequencies falls on a metallic surface in a vacuum; a graph of the maximum kinetic energy of electrons ejected from the surface as a function of the frequency of the electromagnetic radiation is shown here. No photoelectrons are ejected from this metal when the frequency of the radiation is less than f_0. Use the choices below in answering Questions 9 and 10. (In each choice, the dashed line shows the original graph.)



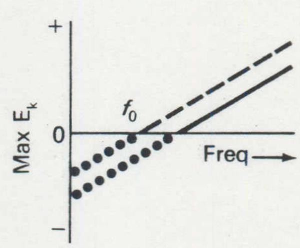
A



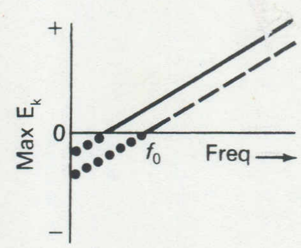
B



C



D



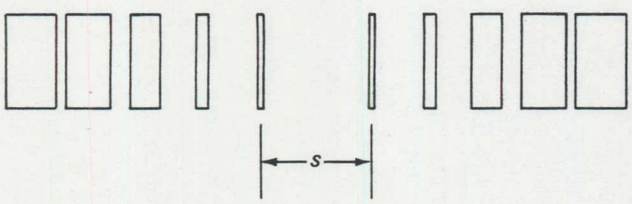
9. If the intensity of the radiation falling on the surface is increased to a new value, which of the graphs shows as a solid line the maximum kinetic energy of the ejected electrons as a function of the frequency of the incident radiation?

(A) A
(B) B
(C) C
(D) D
(E) None of the above.

10. A second metallic surface emits photoelectrons when electromagnetic radiation falls on it whose frequency is less than f_0. Which of the graphs shows as a solid line the maximum kinetic energy of the ejected electrons as a function of the frequency of the incident radiation on this second metallic surface?

(A) A
(B) B
(C) C
(D) D
(E) None of the above.

11. Suppose you hold two razor blades together (each 1.5×10^{-2} cm thick) and scratch a graphite coating on a glass slide. When you look through the slide at a narrow source of red light 400 cm distant, you observe the pattern shown below. From the information given, can you determine the wavelength of red light?



(A) Yes; measure s and use the expression:

$$\lambda = \frac{1.5 \times 10^{-2} s}{(2 - 1/2)400}$$

(B) Yes; measure s and use the expression:

$$\lambda = \frac{3.0 \times 10^{-2} s}{(2 - 1/2)400}$$

(C) Yes; measure s and use the expression:

$$\lambda = \frac{1.5 \times 10^{-2} s}{2 \times 400}$$

(D) No; you do not know the separation of the slits you have scratched.
(E) No; you have made only a single slit of unknown width.

FOR QUESTIONS 12–15:

The energy-levels for a hydrogenlike atom are given below:

$n = \infty$	18 eV	$n = 3$	12 eV
$n = 5$	17 eV	$n = 2$	8 eV
$n = 4$	15 eV	$n = 1$	0 eV

Given:

$c = 3 \times 10^8$ m/s
$h = 6.6 \times 10^{-34}$ J•s
1 eV $= 1.6 \times 10^{-19}$ J

12. The ionization potential of this atom is

(A) 18 volts.
(B) 10 volts.
(C) 8 volts.
(D) 0 volts.
(E) impossible to compute from the data given.

13. The energy of the photon emitted when this atom goes from the state $n = 3$ to the state $n = 2$ is

(A) 4 eV.
(B) 6 eV.
(C) 8 eV.
(D) 10 eV.
(E) 12 eV.

14. The frequency of the photon emitted when the atomic system goes from the state $n = 2$ to the state $n = 1$ is given most nearly by

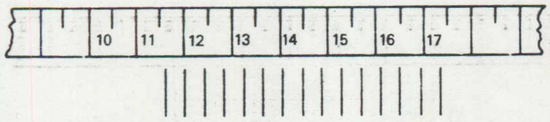
(A) 1×10^{15} Hz
(B) 2×10^{15} Hz
(C) 3×10^{15} Hz
(D) 5×10^{15} Hz
(E) 8×10^{15} Hz

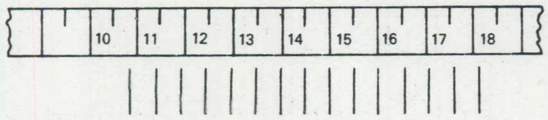
15. An electron having 10 eV of kinetic energy interacts with this atom when it is in the ground state. A possible value for the kinetic energy of this electron *after* this interaction is

(A) 0 eV.
(B) 2 eV.
(C) 8 eV.
(D) 18 eV.
(E) 28 eV.

16. Suppose each of the drawings (1) and (2) represents the pattern observed during a Young's experiment, in which light of a single color passed through a double slit. To compare the wavelengths of the light producing the two patterns, which of the following would you need to know in addition to the information you receive from the drawing?

I. Slit separation
II. Slit width
III. Distance from observer to the source

(1) 

(2) 

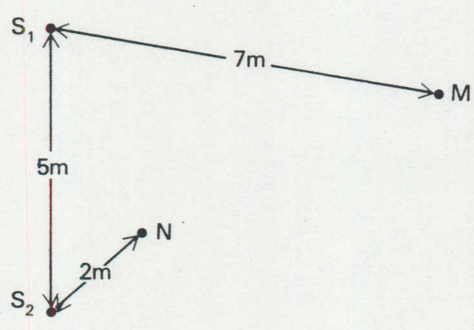
(A) I only
(B) II only
(C) III only
(D) I and III only
(E) I, II and III

17. Let λ_{10} be the de Broglie wavelength of an electron of 10 eV kinetic energy, and λ_{1000} be that of an electron of 1000 eV kinetic energy. What is the value of the ratio $\lambda_{10}/\lambda_{1000}$?

(A) 1/100
(B) 1/10
(C) 1
(D) 10
(E) 100

FOR QUESTIONS 18 AND 19:

Two very small identical loudspeakers, each of which is radiating sound uniformly in all directions, are placed at points S_1 and S_2 as shown in the diagram. They are connected to a source so that they radiate in phase with each other, the wavelength of the sound emitted being 2.00 meters. No sound is reflected.



18. Point *M*, a nodal point, is 7 meters from S_1 and at least 7 meters from S_2. The smallest distance that *M* can be from S_2 is

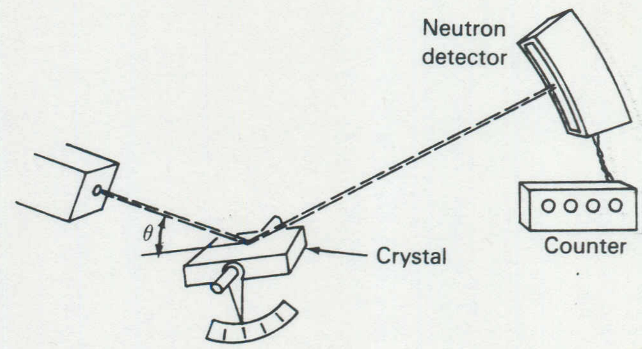
(A) 7 meters
(B) 8 meters
(C) 9 meters
(D) 10 meters
(E) 12 meters

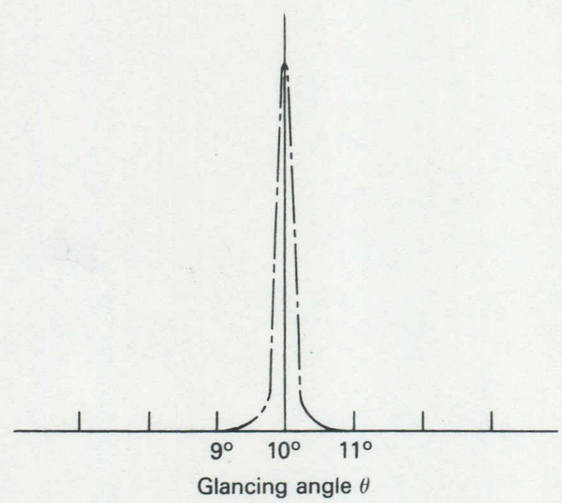
19. Suppose that loudspeaker S_2 is adjusted so that it radiates with a phase delay of $\frac{1}{2}$ with respect to S_1. Point *N*, which is 2 meters from S_2, will be a nodal point if its distance from S_1 is

(A) 2 meters
(B) 3 meters
(C) 4 meters
(D) 5 meters
(E) 7 meters

FOR QUESTIONS 20 AND 21:

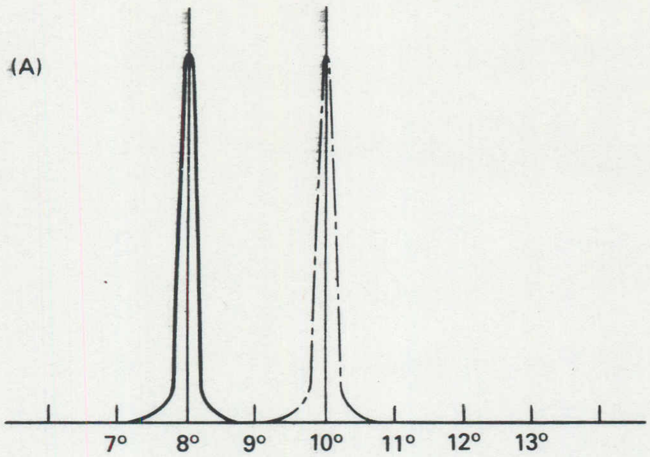
The drawing shows an experimental arrangement to detect interference effects in neutrons hitting a salt crystal. The number of counts per unit time as a function of angle for neutrons moving at 4×10^3 m/s is shown in the graph.



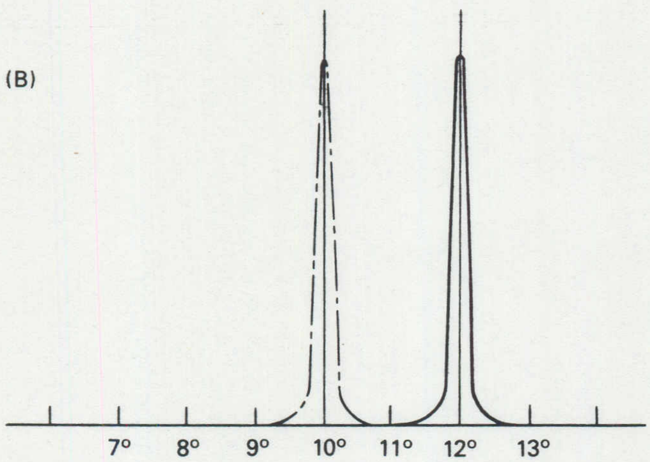


20. Which graph following could show the number of counts per unit time as a function of angle if the speed of the neutrons had been 5×10^3 m/s instead of 4×10^3 m/s? (In each case the original graph is shown as a dotted line.)

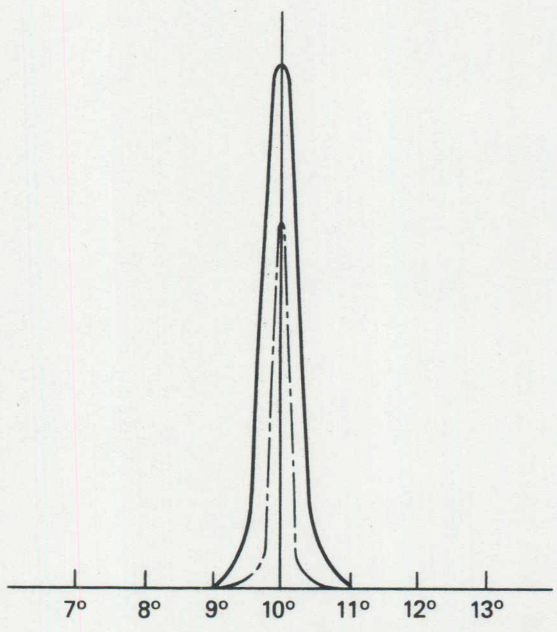
(A)



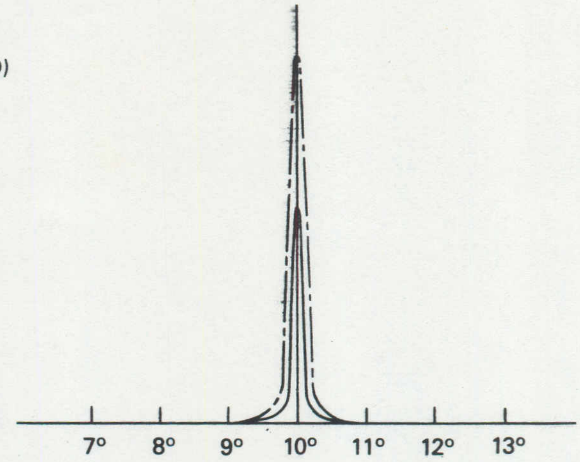
(B)



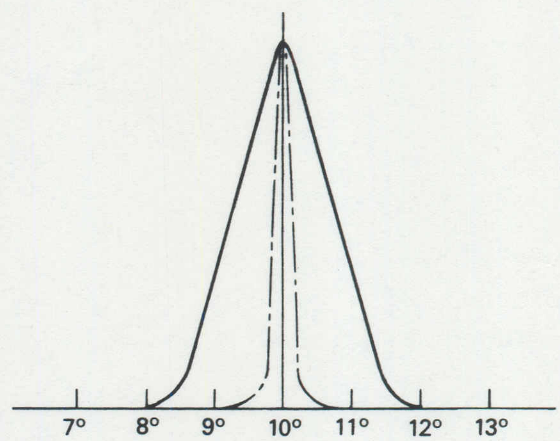
(C)



(D)



(E)

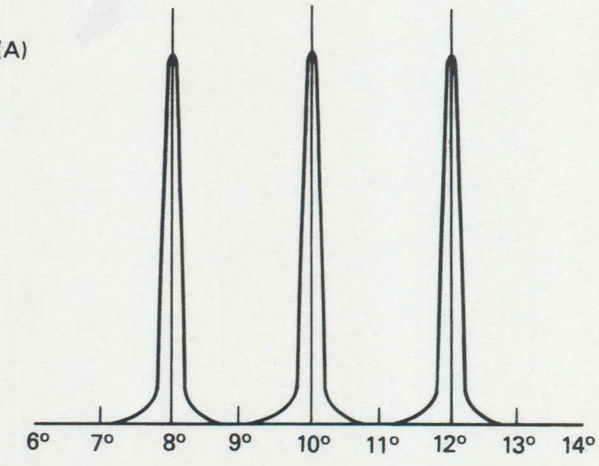


(A) A (B) B (C) C (D) D (E) E

20........A

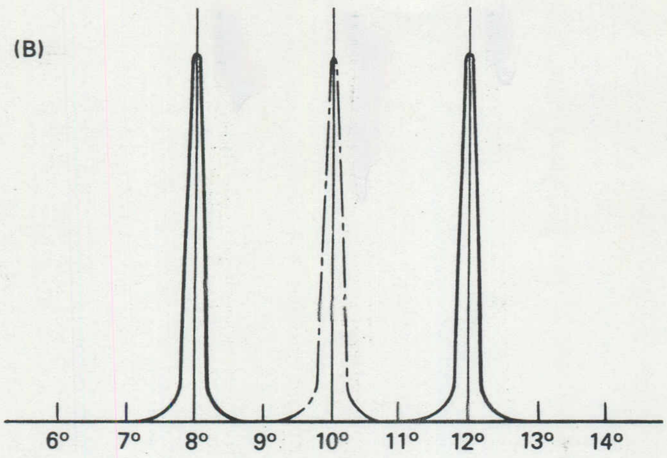
21. Which graph below could show the number of counts per unit time as a function of angle if the neutrons had no wave properties but followed exact trajectories instead?

(A)

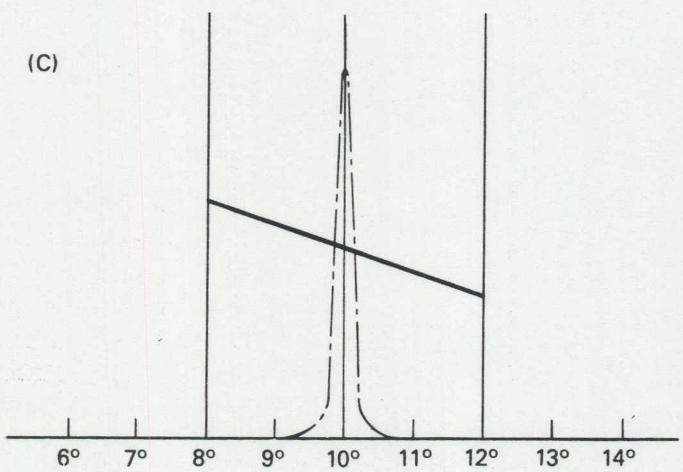


Name

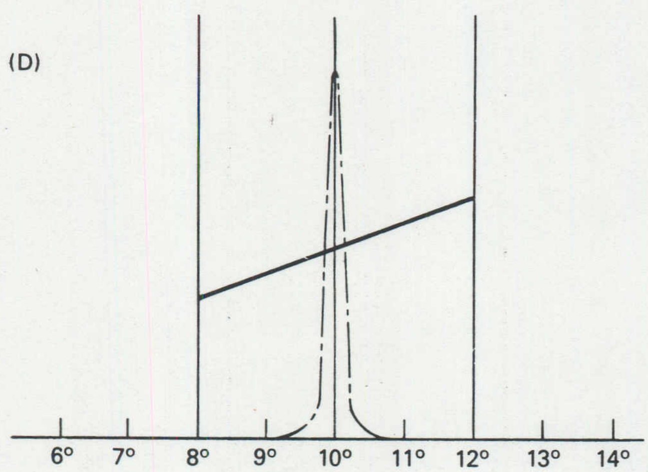
(B)



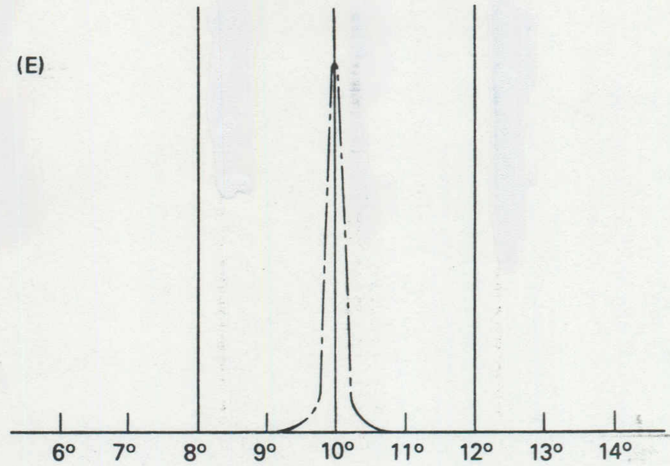
(C)



(D)

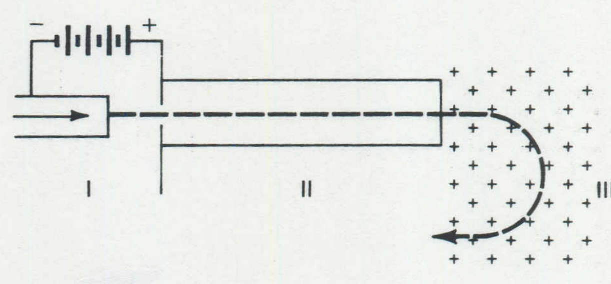


(E)



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

22. The apparatus shown is in a vacuum; electrons emitted from the cathode pass through region I, through a hole in the anode, and into a metal tube (region II); on leaving the tube they enter a uniform magnetic field directed downward into the paper (region III).



In which of the regions does an electron emit electromagnetic waves?

(A) I only
(B) II only
(C) III only
(D) I and III only
(E) I, II and III

accelerated through a potential difference V_a and then introduced into mercury vapor. After passing through the mercury vapor, the remaining energy of the electrons was measured. In answering the questions, consider only the following prominent energy levels for mercury, expressed in electron volts (eV), above the ground state: 4.9 eV, 6.7 eV, 8.8 eV, and 10.4 eV. (10.4 eV is the ionization energy.)

23. If an electron entered the vapor with an energy of 3.0 electron volts, the amount of energy it would have after passing through the vapor would be very close to

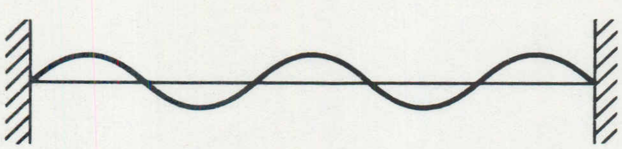
(A) 1.8 eV only.
(B) 3.0 eV only.
(C) 4.9 eV only.
(D) 1.8 eV or 2.1 eV only.
(E) 1.8 eV, 2.1 eV, or 3.0 eV.

24. If an electron entered the vapor with an energy of 8.0 electron volts, the amount of energy it would have after passing through the vapor would be very close to

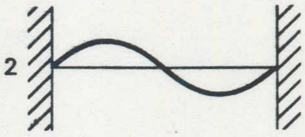
(A) 4.9 eV only.
(B) 0.8 eV or 8.0 eV only.
(C) 4.9 eV or 6.7 eV only.
(D) 4.9 eV, 6.7 eV, or 8.0 eV.
(E) 1.3 eV, 3.1 eV, or 8.0 eV.

The standing wave describing each of the components of the momentum p_x, p_y, p_z of an electron confined in a cubical box is given by Fig. 1.

1



2



25. What is the value of the ratio E_1/E_2 of the energies of these two electrons in the situation shown?

(A) $(5/2)^2$
(B) 5/2
(C) 1
(D) 2/5
(E) $(2/5)^2$

1.	C	6	E	11	E	16	D	21	E
2.	D	7	A	12	A	17	D	22	D
3.	A	8	C	13	A	18	B	23	B
4	C	9	E	14	B	19	C	24	E
5	B	10	D	15	B	20	A	25	C