زبانهای خارجی

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English
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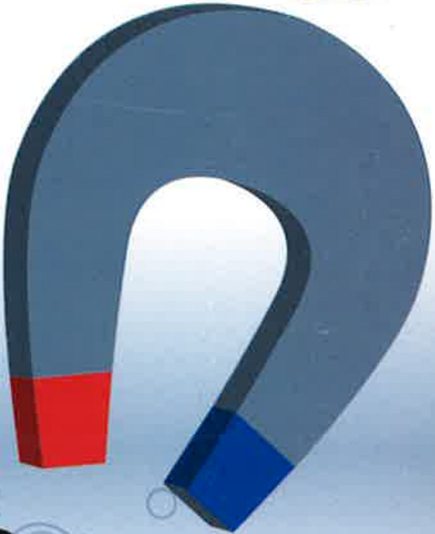

Physics

Esmail Faghih, PhD

English

for the Students of

Physics

Esmail Faghih, PhD

Tehran
2016/1394

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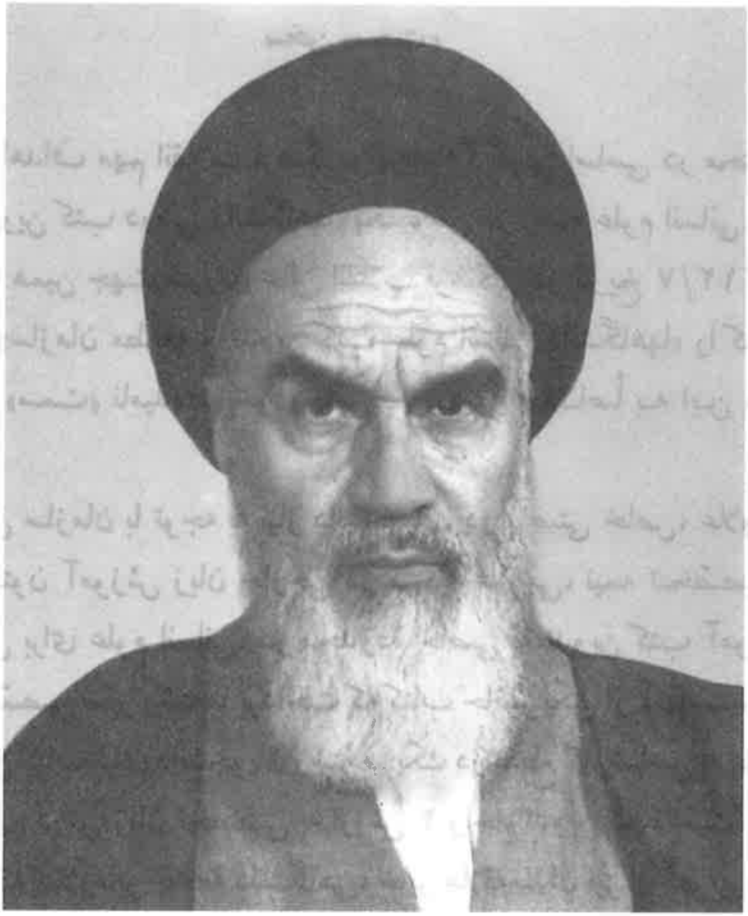
بسم الله الرحمن الرحیم

In the Name of Allah

the Compassionate, the Merciful



پیشتر احتیاج به زبان ـ زبانهای خارجی ـ نبود امروز احتیاج است به این، یعنی جزو برنامه تبلیغات مدارس باید زبان باشد و زبانهای زنده دنیا، آنهایی که در همه دنیا شایعتر است.

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سخن «سمت»

یکی از اهداف مهم انقلاب فرهنگی، ایجاد دگرگونی اساسی در محتوا و شیوهٔ تدوین کتب درسی دانشگاهها، بخصوص در زمینه علوم انسانی بوده است. به همین جهت شورای عالی انقلاب فرهنگی در تاریخ ۶۳/۱۲/۷ تاسیس «سازمان مطالعه و تدوین کتب علوم انسانی دانشگاهها» را که به اختصار «سمت» نامیده می‌شود، تصویب کرد تا اختصاصاً به این مهم بپردازد.

این سازمان با توجه به نیاز دانشجویان، در فرصتی خاص، علاوه بر تدوین متون آموزش زبان خارجی در مرحله عمومی، نیمه تخصّصی و تخصّصی برای علوم انسانی، در محدودهٔ خاصی به تدوین کتب آموزش زبان تخصّصی سایر رشته‌ها پرداخت که کتاب حاضر یکی از آنهاست.

این کتاب برای دانشجویان رشتهٔ فیزیک در مقطع کارشناسی به عنوان منبع اصلی درس زبان تخصصی به ارزش ۲ واحد تدوین شده است. امید می‌رود که علاوه بر جامعهٔ دانشگاهی، سایر علاقه‌مندان نیز از آن بهره‌مند شوند.

دشواری چنین کاری بر دانشمندان و صاحبنظران پوشیده نیست و به همین جهت مرحلهٔ کمال مطلوب آن، باید بتدریج و پس از پیشنهادهای اصلاحی ارباب نظر به دست آید و انتظار دارد که این بزرگواران از این همکاری دریغ نورزند.

Table of Contents

Unit	Title	Page
1.	Fluid Mechanics	1
2.	Electricity	13
3.	Magnetism	28
4.	Optics	45
5.	Lasers	60
6.	Modern Physics	75
7.	Quantum Mechanics	92
8.	Elementary Particles	105
9.	Relativity	118
10.	Nuclear Physics	131
11.	Reactor Physics	145
12.	Thermodynamics	159
13.	Solid State Physics	173
14.	Statistical Mechanics	188
15.	The Microscopic Theory of Superconductivity	203
16.	Astronomy	218
	References	241

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Needless to say, I alone am responsible for imperfections and shortcomings which no doubt remain.

Section One: Reading Comprehension

Fluid Mechanics

The Physical Properties of Fluids

The defining property of fluids, embracing both liquids and gases, lies in the ease with which they may be deformed. A piece of solid material has a definite shape, and that shape changes only when there is a change in the external conditions. A portion of fluid, on the other hand, does not have a preferred shape, and different elements of a homogeneous fluid may be rearranged freely without affecting the macroscopic properties of the portion of fluid. The fact that relative motion of different elements of a portion of fluid can, and in general does, occur when forces act on the fluid gives rise to the science of fluid dynamics.

The distinction between solids and fluids is not a sharp one, since there are many materials which in some respects behave like a solid and in other respects like a fluid. A 'simple' solid might be regarded as a material of which the shape, and the relative positions of the constituent elements, change by a small amount only, when there is a small change in the forces acting on it. Correspondingly, a 'simple' fluid (there is no one term in general use) might be defined as a material such that the relative positions of the elements of the material change by an amount which is not small when suitably chosen forces, however small in magnitude, are applied to the material. But, even supposing that these two definitions could be made quite precise, it is known that some materials do genuinely have a dual character. A thixotropic substance such as jelly or paint behaves as an elastic solid after it has been allowed to stand for a time, but if it is subjected to severe distortion by shaking or brushing it loses its elasticity and behaves as a liquid. Pitch behaves as a solid normally, but if a force is imposed on it for a very long time the deformation increases indefinitely, as it would for a liquid. Even more troublesome to the analyst are those materials like concentrated polymer solutions which may simultaneously exhibit solid-like and fluid-like behaviour.

Fortunately, most common fluids, and air and water in particular, are quite accurately simple in the above sense. In this unit we shall suppose that the fluid under discussion cannot withstand any tendency by applied forces to deform it in a way which leaves the volume unchanged.

However, it should be noted that a simple fluid may offer resistance to attempts to deform it; what the definition implies is that the resistance cannot prevent the deformation from occurring, or, equivalently, that the resisting force vanishes with the rate of deformation.

The distinction between liquids and gases is much less fundamental, so far as dynamical studies are concerned. For reasons related to the nature of intermolecular forces, most substances can exist in either of two stable phases which exhibit the property of fluidity, or easy deformability. The density of a substance in the liquid phase is normally much larger than that in the gaseous phase, but this is not in itself a significant basis for distinction since it leads mainly to a difference in the magnitudes of forces required to produce given magnitudes of acceleration rather than to a difference in the types of motion. The most important difference between the mechanical properties of liquids and gases lies in their bulk elasticity, that is, in their compressibility. Gases can be compressed much more readily than liquids, and as a consequence any motion involving appreciable variations in pressure will be accompanied by much larger changes in specific volume in the case of a gas than in the case of a liquid. Appreciable variations in pressure in a fluid must be reckoned with in meteorology, as a result of the action of gravity on the whole atmosphere, and in very rapid motions, of the kind which occur in ballistics and aeronautics, resulting from the motion of solid bodies at high speed through the fluid. There are common circumstances in which motions of a fluid are accompanied by only slight variations in pressure, and here gases and liquids behave similarly since in both cases the changes in specific volume are slight.

Batchelor, G. K. (1970: pp. 1-2).

Part I. Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The main characteristic of fluids is their easy deformability.

.... 2. It is much easier to distinguish between liquids and gases than between fluids and solids.

.... 3. It is understood from the passage that the more the bulk elasticity of a material is, the variation in pressure would result in the less change in its specific volume.

.... 4. The distinctive characteristic of liquids from gases is that liquids cannot be compressed as readily as gases.

.... 5. Meteorology is the science that studies significant variations in pressure resulting from the motion of solid bodies at high speed through the fluid.

.... 6. If the changes in specific volume of liquids and gases are slight, the result would be slight variation in pressure, and hence liquids and gases would behave differently.

B. Choose a, b, c, or d which best completes each item.

1. The theoretical foundation of the science of fluid dynamics lies in the fact that ....
   a. when there is a change in the external conditions of fluid, its shape will change
   b. the definite shape of both liquids and gases may be deformed
   c. when forces act on a portion of fluid, it will result in a relative motion in the elements of that fluid
   d. it is extremely difficult to change the preferred shape of both liquids and gases
2. The reason that it is hard to differentiate solids from fluids lies in the fact that ....
   a. both of them may be deformed
   b. some materials would change their volume under pressure
   c. both of them have a definite shape
   d. some materials have the characteristics of both of them
3. Pitch and paint would show the characteristics of a liquid if ....
   a. they are left to rest for a while
   b. the relative positions of their constituent elements change
   c. they are subjected to severe or prolonged distorting force
   d. the relative force acting on them is small in magnitude
4. It is assumed in this unit that the term fluid refers to any material that ....
   a. can resist any force acting on it
   b. any force acting on it would change its volume
   c. its resisting force to deformation gradually would increase
   d. the external force acting on it would change its macroscopic characteristics
5. The density of a substance in the liquid phase ....
   a. is a significant characteristic which is dealt with in aeronautics
   b. leads to a difference in the types of motion
   c. is an important distinctive feature between liquids and gases

d. leads to a difference in the magnitude of the forces to produce acceleration

6. According to the passage, a change in the shape of fluid would not ....

a. affect the relative positions of its elements

b. result in its deformability

c. affect its macroscopic characteristics

d. result in its deformation indefinitely

C. Answer the following questions orally.

1. What would happen to the macroscopic characteristics of some fluid if its elements were rearranged?
2. What is meant by a 'simple' fluid?
3. When will a thixotropic substance behave as a liquid?
4. When will the deformation of a liquid increase indefinitely?
5. What is the most important difference between the mechanical characteristics of gases and liquids?
6. Why will a change in pressure result in a larger change in the specific volume of a gas than in a liquid?
7. Why will the resisting force of a simple fluid against deformability vanish with the rate of deformation?

Part II. Language Practice

A. Choose a, b, c, or d which best completes each item.

1. A substance which takes .... of the vessel containing it is fluid.

a. the configuration　　c. the form

b. the figure　　d. the shape

2. The coefficient of compressibility of a substance is .... in square metres per newton.

a. assessed　　c. measured

b. estimated　　d. weighed

3. The property of a body or material of resuming its .... form and dimensions when the forces acting upon it are removed is called elasticity.

a. novel　　c. primary

b. original　　d. unique

4. Hard dark substance which .... to viscous tarry liquids is called pitch.

a. disappear　　c. melt

b. dissolve　　d. thaw

5. The .... of unit volume of a substance is its density.

a. accumulation c. mass
b. bulk d. size

6. The rate of change of viscosity with .... is called thixotropy.

a. age c. period
b. era d. time

7. The product of the chemical union of two or more molecules of the same compound to form larger molecules, resulting in .... of a new compound of the same empirical formula but of a greater molecular weight is polymer.

a. the configuration c. the construction
b. the conformation d. the formation

B. Fill in the blanks with the appropriate form of the words given.

1. Resistant

a. We begin the discussion of .... with the case of perfectly smooth pipes.
b. A narrow water pipe .... the flow of water more than a wide one.
c. We say that a material is .... to heat when it is not easily damaged or destroyed by the application of heat.

2. Concentrate

a. The disturbance effect is practically completely .... along the Mach waves.
b. A strong .... of a dissolved substance is one which does not have much liquid in it.
c. A highly .... solution was used in the experiment.

3. Compress

a. The reciprocal of the bulk modulus is called the ....
b. It is not possible to treat the dynamics of .... fluids without taking account of their thermal properties.
c. If a mass of gas is .... isothermally, the average translational energy of a molecule remains constant.

4. Deform

a. Liquids and gases may be easily ....
b. The property of .... is characteristic of liquids.
c. If the forces are sufficiently large for the .... to cause a break in the molecular structure of the body, it loses its elasticity.
d. A piece of solid material has a definite shape and therefore is ....

5. **Constituent**

a. A .... part of a thing is one which essentially belongs to that thing and which makes it what it is.

b. Geologists are interested in the .... of the rocks in the regions they study.

c. A thing is .... by the parts or features which make it what it is.

d. Oxygen is one of the .... of water.

C. Fill in the blanks with the following words.

incompressible	substances	shearing	motions
theoretically	negligible	vapours	phases
distinction	rheology	possess	denser

A fluid is defined to be a material substance which cannot sustain a shearing stress when it is at rest. The nature of shearing stress is a consequence of the definition that relative .... of the elements of a mass of fluid can be set up by very small (.......... infinitesimal) forces and continuous distortion occurs. In more popular language, fluids .... the property of flowing freely.

The definition calls for two comments. First, nothing is said about the rate of movement under the action of shearing stresses. Hence .... which respond very sluggishly to applied .... stresses may yet be fluids. Second, substances other than fluids may flow but they do not flow under the action of exceedingly small forces. The study of such substances falls within the province of ....

Fluids are conventionally classified as (a) liquids or (b) gases and .... These are two possible .... of a fluid which, when they coexist, form an interface (or free surface), and the liquid is the .... of the two. From the point of view of mechanics the important .... is between compressible and incompressible fluids. Of course, no fluid is strictly incompressible but in ordinary circumstances the compressibility of most liquids is so small that its influence on the flow is .... Throughout this text it will be assumed, unless the contrary is stated, that liquids are .... Gases and vapours, on the other hand, are highly compressible, although if the distorting forces are small a gas may behave as if incompressible.

D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. In kinematic theory we study the motions of fluids in a very general way but we do not attempt to answer the question as to how a fluid with given physical properties does move in given circumstances.

b. The answer to this question must be based on dynamical arguments.

c. It appears that when a body moves through a fluid which is at rest, except as disturbed by the body itself, the flow is irrotational except in the *boundary layer* adjacent to the surface of the body and in the *wake*, which is really an extension of the boundary layer.

d. Thus the special attention given to irrotational flow is justified; we can go further and say truly that the theory of irrotational flow is an essential foundation for the dynamics of fluids.

e. However, dynamical theory shows the importance of the type of motion called irrotational, i.e., that in which the vorticity is zero.

1	2	3	4	5

Section Two: Further Reading

Kinematics of Fluids

Kinematics is the geometry of motion. Thus, the kinematics of fluids is the science of the motion of fluids considered in abstraction from the forces which cause or accompany the motion. The subject has two main aspects:

(a) The development of methods and techniques for describing and specifying the motions of fluids.

(b) The determination of the conditions for the kinematic possibility of fluid motions, i.e., the exploration of the consequences of continuity in the motion.

A thorough study of the kinematics of fluids is a necessary preliminary to the study of the dynamics of fluids; in the latter subject we are concerned with the manner in which fluids do in fact move in given circumstances and with the forces accompanying the motion. It is found that the actual motions of fluids in many important cases conform to simple kinematic types, so purely kinematic investigations carry us very far into the general theory of fluid motion.

The kinematics of fluids presents problems of much greater complexity than does the kinematics of rigid bodies and requires quite different theoretical methods for its treatment. For a rigid body moving in a plane, the velocities of *all* its points at a given instant become definite and calculable when the two components of the velocity of one point and the angular velocity are given. For plane motion the rigid body thus has just three degrees of freedom. However, the fluid occupying a given region has infinitely many degrees of freedom. In spite of this, the motion is not completely arbitrary for there remains the condition that two fluid elements cannot occupy the same position at the same time.

Unless the contrary is stated, we shall suppose for a liquid that cavitation does not occur, i.e., adjacent elements do not become separated, leaving gaseous regions within the liquid.

Description and Specification of Fluid Motion

We consider a very small element of fluid which we call a fluid particle; this is so small that the relative velocities of its parts are negligible and, so far as position is concerned, it can be regarded as a geometric point. However, we must not forget that our fluid particle has a definite mass and a volume, which, in the case of an incompressible fluid, is constant. At any given instant the fluid particle at a point P has a definite velocity which can conveniently be specified by its components referred to fixed rectangular axes. In the most general case the velocity depends on the time t and on the coordinates of P but there are two important and simple cases:

(a) The motion is said to be *steady* when the velocity at any point with fixed coordinates is the same at all instants.

(b) The motion is said to be *uniform* at the instant considered when the velocity is the same for all fluid particles. A uniform motion may also be steady.

With regard to the definition (a), it should be noted that a motion may be steady for one set of reference axes and unsteady for another. For example, let us consider an aircraft flying with constant speed in a horizontal straight line and without rotation. Then, if we take reference axes fixed in the aircraft, the motion of the air will be steady because the velocity at a point with fixed coordinates is independent of time. But if we take axes fixed to the earth the motion of the air will be unsteady. We shall always suppose that the reference axes are fixed in direction and that the origin is at rest or in unaccelerated motion.

There are two important and commonly used methods of specifying fluid motion. The first, known technically as the *Lagrangean method,* may be described as *historical* since we follow the history of each individual fluid particle. The particle may be identified by its spatial coordinates at the instant $t=0$; its coordinates at any later time t are then functions of t and of these initial coordinates. The *path of a particle* is the curve of fundamental importance when the motion is considered from this point of view. The second, known technically as the *Eulerian method,* may be described as the *cinematographic* method since the basic conception is the state of velocity throughout the whole region occupied by the fluid *at one instant;* the complete state of motion is given by a succession of such instantaneous pictures of the state of flow. In accordance with the definition, the flow picture is constant when the motion is steady. In the Eulerian method the curve of fundamental importance is the *streamline.*

Duncan, W. J., Thom, A. S., & Young, A. D. (1985: pp. 36-37).

Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The results of the continuity of the motion of fluids are studied by the science of the geometry of motion.

.... 2. In most of the cases, the explanation of simple kinematic types would not be applicable to the motion of fluids in given circumstances.

.... 3. To achieve a better understanding of the motion of some fluid in a special situation, one should try to understand the motion of fluids in abstraction first.

.... 4. If the velocity of all fluid particles studied is the same, the motion is referred to as being steady.

.... 5. In the example of an aeroplane flying at a constant speed, the motion with reference to the earth will be steady.

.... 6. It is understood from the passage that a very small element of fluid called a fluid particle will have a definite mass but no volume.

B. Choose a, b, c, or d which best completes each item.

1. The manner of the motion of fluids in specific circumstances is studied by ....

a. Lagrangean method　　　c. cinematographic method
b. kinematics　　　d. the dynamics of fluids

2. The science of the motion of fluids in abstraction ....
   a. cannot explain the motion of fluids at one instant
   b. is capable of justifying the accompanying forces of the motion of fluids
   c. in many cases explains the motion of fluids in given circumstances
   d. is not helpful in explaining the exceptional problems of the theory of fluid motion
3. The reason that Eulerian method of specifying fluid motion can also be referred to as cinematographic is that ....
   a. according to the definition when the motion is uninterrupted the flow picture will be constant
   b. Eulerian method studies the velocity of the region occupied by the fluid at one instant
   c. the streamline is the curve of fundamental importance
   d. in order to get a complete picture of the state of flow, a series of successive instantaneous pictures are needed
4. The reason that the subject matter of fluid kinematics is more complex than the solid bodies lies in the fact that ....
   a. the methods and techniques used for describing and explaining fluids are more complex than solid bodies
   b. unlike rigid bodies, fluids in given circumstances have unlimited degrees of freedom
   c. fluids show a continuity in their motion whereas rigid bodies do not
   d. usually the motion of fluids is of steady type but that of rigid bodies is not
5. It is understood from the passage that ....
   a. once a fluid motion for one axis is steady it will be the same for all other axes
   b. the steadiness or unsteadiness of a fluid motion is related to the velocity of all fluid particles
   c. in regards to different axes a fluid motion might be steady and unsteady simultaneously
   d. generally speaking it is impossible to determine the definite velocity of the fluid particles
6. In order to calculate all of the velocities of a rigid body moving in a plane .... will be needed.
   a. two components of the velocity at one point
   b. two elements occupying the same position

c. the angular velocity

d. both a and c

C. Write the answers to the following questions.

1. When is the path of a particle regarded as constituting the curve of fundamental importance?
2. Which method of specifying fluid motion suggests that when the motion is steady the flow picture is constant?
3. What does cavitation mean?
4. Why is it suggested in the passage that the motion of fluids is not completely arbitrary?
5. Why is the kinematics of fluids harder to study than the kinematics of rigid objects?
6. Why is an understanding of the kinematics of fluids necessary for the study of the dynamics of fluids?

Section Three: Translation Activities

A. Translate the following passage into Persian.

Flow Classification

Open channel flow may be classitied as steady or unsteady, uniform or nonuniform. *Steady uniform flow* occurs in long inclined channels of constant cross-section, in those regions where *terminal velocity* has been attained, i.e., where the head loss due to the flow is exactly supplied by the reduction in potential energy due to the uniform decrease in elevation of the bottom of the channel. The depth for steady uniform flow is called the *normal depth.*

Steady non-uniform flow occurs in a channel when the cross-sectional area or the flow depth and hence the average velocity change along the flow direction; the discharge remaining constant with time. This is further classified as *gradually varied flow* for gradual changes in depth or section, and *rapidly varied flow* for pronounced changes in depth or section within a short distance. Hydraulic jump is an example of this type of flow.

Unsteady uniform flow rarely occurs in open-channel flow, and is, therefore, not discussed. *Unsteady non-uniform flow* is common but is difficult to analyse. Wave motion is an example of this type of flow.

Flow is also classified as tranquil or rapid. When flow occurs at low velocities so that a small disturbance can travel upstream, it is said to be *tranquil or sub-critical flow.* Such a flow is controlled by the downstream conditions and for it, the Froude number, *Fr*, is less than unity. When flow occurs at such high velocities that a small disturbance is swept downstream, it is said to be *rapid or shooting or supercritical* flow.

B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. aeronautics ....
2. ballistics ....
3. boundary ....
4. compressibility ....
5. deformation ....
6. density ....
7. disturbance ....
8. elastic solid ....
9. fluid dynamics ....
10. gravity ....
11. homogeneous fluid ....
12. intermolecular ....
13. irrotational flow ....
14. isothermally ....
15. meteorology ....
16. modulus ....
17. normal depth ....
18. oscillate ....
19. rheology ....
20. shearing stress ....
21. specific volume ....
22. steady uniform flow ....
23. terminal velocity ....
24. thermal properties ....
25. thixotropic ....
26. tranquil flow ....
27. translational energy ....
28. vorticity ....
29. wake ....

Unit 2

Section One: Reading Comprehension

Electricity

Gauss' Law and Conductors

In what follows we shall speak of the electric field within a conductor. Let us first be clear about what this means. If the electric field is measured over a volume of space which is small compared with the distance between particles on an atomic scale, we see nothing but point-charges; so the field within any material, whether conductor or nonconductor, changes rapidly as we approach and recede from these point-charges. For our purposes we need not consider such small volumes, and by the electric field within a material we shall mean the average force acting on a unit positive charge over a volume that is large enough to include many charged particles, but small enough to allow us to speak of the electric field at a 'point'.

The electric field within an insulated charged conductor is exactly zero. By using Gauss' law we can immediately deduce an important consequence of this fact. Imagine a gaussian surface to be located just inside the outer surface of a charged conductor of arbitrary shape, as shown in Figure 2-1. The conductor may be a solid piece of metal or one with interior cavities. Since the boundary of the gaussian surface lies on the interior of the conductor, the electric field at every point on the gaussian surface is zero; consequently, the electric flux through the surface is zero. From Gauss' law, if $\phi_E=0$, then $q=0$, and there is *no* (net) charge inside the surface of a charged conductor. Thus, atoms within the interior of the conductor are neutral, while any excess or deficiency of electrons occurs in a thin layer of atoms at the conductor's surface. We saw earlier that the electric field within a *spherically symmetric* shell of charge is zero. Our present result for *conductors* is more general: The interior field is zero for *any* shape and for

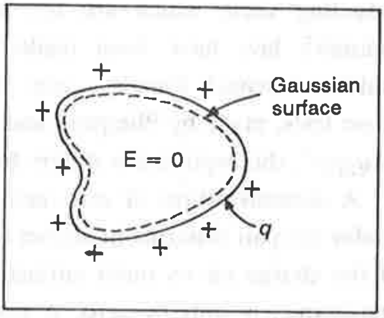


Figure 2-1. Electrical Conductor With a Gaussian Surface Chosen to Lie Just Inside the Conductor's Outside Surface.

any charges on the exterior surface.

The external electric field near the conductor's surface is always perpendicular to the surface at that point. This is always the case for a conductor in electrostatic equilibrium; for, if the electric field were not along the normal to the surface, there would be a component lying along the surface. This component would then act on free electric charges at the surface of the conductor and change the charge distribution. Since the charge distribution on a conductor in equilibrium is fixed, the electric field is always normal to the surface.

The assertion that the net electric charge within a conductor, quite apart from external electric fields or charges on the surface, is always zero, is a consequence of Gauss' law. If we test this assertion by experiment, we test the correctness of Gauss' law, which is to say that we test Coulomb's law and the inverse-square variation in the electric interaction between point-charges. If the net charge within a conductor were found to be just slightly different from zero, the exponent of *r* in Coulomb's law would differ from 2 by some very small amount. Such experimental attempts at seeking a net charge inside a conducting shell, which are the most sensitive tests of the exponent in Coulomb's law, have been made by many physicists, including Benjamin Franklin, Michael Faraday, and Henry Cavendish. The most recent and precise tests, made by Plimpton and Lawton in 1936, show that in the relation $F=kq_1q_2/r^n$, the exponent n differs from 2 by no more than 1 part in 10^9.

A demonstration of zero net charge inside a conductor is the famous Faraday ice-pail experiment shown in Figure 2-2. The conductor is an ice pail, and the charge on its outer surface, indicated by the charge on the attached electroscope, is initially zero. A positively charged object is introduced into the interior of the conductor. Negative charges appear on the inner surface and positive charges of the same magnitude on the outer surface of the pail. We may say that the charged object 'induces' charges on the inner and outer surface of the conductor. Then the object is touched to the inside of the conductor and annuls all the induced charge on this inner surface (Figure 2-2*c*). Finally, when the object is removed, the electroscope shows the same charge as in Figure 2-2*b*. The object itself is found to have zero charge. The experiment shows that the charge originally carried by the object has been transferred entirely to the exterior of a conductor.

Another important example of zero field inside a conductor is in the effects of external charges. Any static electrical effect external to a conductor is not felt by charges within the conductor. Therefore, a closed conductor (or

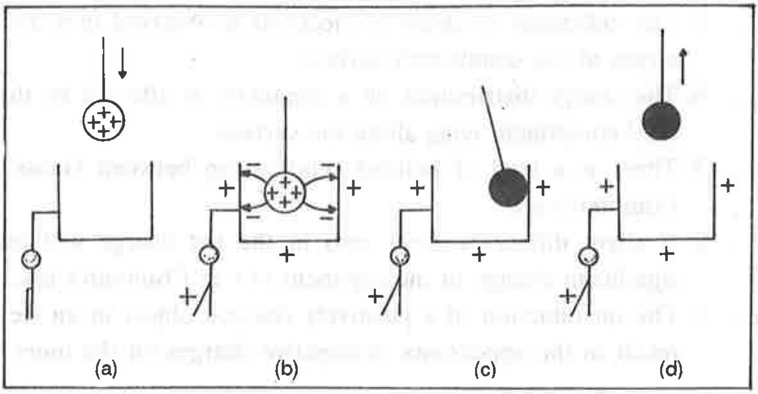


Figure 2-2. Stages in the Transfer of Charge From a Charged Object to the Outside of a Hollow Conductor, Whose State of Charged Is Indicated by the Attached Electroscope. *(a)* The charged object is outside. *(b)* The charged object is within the conductor, and equal and opposite charges are found on the inside and outside of the conductor. *(c)* When the object is touched to the conductor's inside, it annuls the charge on the conductor's inner surface and the exterior charge is unchanged. *(d)* The object, now electrically neutral, is removed.

one with only small holes leading to the interior) acts as a perfect shield. This is of practical importance in that electrical apparatus placed within a metallic screen (which is effectively a closed conducting surface) is shielded from any external electrical influence.

Weidner, R. T., & Sells, R. L. (1973: pp. 347-349).

Part I. Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The electric field within any material will change rapidly as its point-charge is approached.

.... 2. Point-charges will be observed in the electric field if they are measured over a large volume of space.

.... 3. In order to draw significant results from Gauss' law, the conductor has to be a solid piece of metal.

.... 4. The fact that the boundary of a gaussian surface is located on the interior of a conductor, plays an important role in the application of Gauss' law.

.... 5. The deficiency or excess of electrons is observed in a thin layer of atoms at the conductor's surface.

.... 6. The charge distribution on a conductor is affected by the electric field component lying along the surface.

.... 7. There is a kind of indirect relationship between Gauss' law and Coulomb's law.

.... 8. A slight difference from zero in the net charge will result in a significant change in the exponent of *r* in Coulomb's law.

.... 9. The introduction of a positively charged object in an ice pail will result in the appearance of negative charges on the inner surface.

B. Choose a, b, c, or d which best completes each item.

1. If we measure the electric field within a conductor, we will observe point-charges, provided that ....
   a. the average force acting on a unit charge is large enough to include many particles
   b. the field within the conductor material does not change so rapidly as to make it impossible
   c. the average force acting on a unit charge is small enough to enable a 'point' to exist
   d. the volume of space is smaller than the distance between particles on an atomic scale
2. The electric flux through a gaussian surface placed inside a charged conductor will be zero because ....
   a. the boundary of the gaussian surface is located on the interior of the conductor
   b. the electric field inside an insulated charged conductor is exactly zero
   c. the electric field within a spherically symmetric shell of charge is zero
   d. the electrical conductor had interior cavities and it was deliberately chosen for the experiment
3. All of the following physicists except .... have tried to arrive at a net charge inside a conducting shell.
   a. Henry Cavendish
   b. Michael Faraday
   c. Benjamin Franklin
   d. Karl Gauss
4. The importance of a closed conductor lies in the fact that it ....
   a. can annul the effects of internal charges
   b. enables the same and equal charges to exist inside it
   c. can shield an electrical apparatus from an external influence
   d. neutralizes the opposite charges outside of it

5. There will always be a component lying along the surface if ....
   a. the electric field is always normal to the surface as a result of the equilibrium
   b. the external electric field near the conductor's surface were not horizontal at that point
   c. the electric field were not along the normal to the conductor's surface
   d. the charge distribution at the surface of the conductor is not changed by the electric charge
6. When a positively charged object is introduced into the interior of the conductor, ...
   a. it cancels all the induced charge of the inner surface
   b. negative and positive charges of the same magnitude are induced
   c. it transfers the original charge of the object to the interior of the conductor
   d. positive and negative charges of different magnitude are induced

C. Answer the following questions orally.

1. What will happen to the outer surface of the pail if a positively charged object is introduced into the interior of the conductor?
2. How can the original charge of the object be transferred to the exterior of the conductor?
3. What kind of conductor will act as a perfect shield?
4. What will happen if the object touches the interior of the conductor?
5. How can an electrical apparatus be shielded from external electrical influences?
6. How can point-charges be observed?
7. How can it be proved that the electric field within an insulated charged conductor is exactly zero?
8. Why are the atoms within the interior of a conductor neutral?
9. Why is the electric field always normal to the surface?

Part II. Language Practice

A. Choose a, b, c, or d which best completes each item.

1. The total electric flux of a closed surface in an electric field which is .... to the electric charge within that surface is called Gauss' law.
   a. commensurable c. proportionate
   b. measurable d. proportional
2. An instrument for detecting .... of an electric charge is called electroscope.

a. the attendance
b. the presence
c. the occurrence
d. the residence

3. All of the following except static charge are .... kinds of electric charges.
   a. the numerous
   b. the several
   c. the many
   d. the various

4. The region near an electric charge, in which a force is .... on a charged particle is referred to as the electric field.
   a. strived
   b. plied
   c. exerted
   d. strained

5. The size of an electric charge is .... in electrostatic units or in electromagnetic units.
   a. appraised
   b. surveyed
   c. measured
   d. rated

6. A region in which a stationary electrically charged particle would be .... to a force of attraction or repulsion as a result of the presence of another stationary electric charge is called the electrostatic field.
   a. submitted
   b. enslaved
   c. complied
   d. subjected

B. Fill in the blanks with the appropriate form of the words given.

1. Vary

a. The speed of sound waves .... with the temperature of the atmosphere, the amount of water in the atmosphere, and the height.

b. The physical law in question is known .... to different scientists.

c. There are now several .... of spaniel.

d. There are .... rates of interest charged on loans made by banks according to government regulations, and these depend on the country's financial circumstances.

2. Attempt

a. He is heavily in debt, and his .... to get out of debt have proved unsuccessful.

b. If they .... to interfere with our arrangements, we will report them to the authorities.

3. Imagine

a. To explain scientific ideas, writers sometimes use .... examples.

b. Don't .... that you know everything.

c. Children are encouraged to use their ....

4. Locate

a. When we go to another country, we should learn something about the .... customs.

b. The climate of a particular .... depends on its attitude and protection from winds as well as on its latitude.

c. Sailors .... their position at sea with the help of charts and accurate chronometers.

d. This map shows the .... of the property I intend to buy.

5. Exceed

a. People often complain that the prices they have to pay for food and other necessary things are ....

b. When a country's imports .... its exports, that country will be in debt.

c. This year there has been an .... of imports over exports.

d. He had a heart attack because he worked .... hard.

6. Distribute

a. Geographers are interested in the ...., on the earth's surface, of such features as mountains seas and forests.

b. The population of a country is .... over the areas of that country.

c. The mail was not delivered yesterday because the .... trades were on strike.

d. The rich man ordered his secretary to give some money .... to the hotel staff, where he had spent the previous night.

7. Introduce

a. The .... of electric typewriters has helped us to reduce staff and office costs.

b. The manager .... modern equipment into the coal mining industry.

c. I refused to write an .... chapter to his new book, because I did not agree with him whole heartedly.

C. Fill in the blanks with the following words.

responsible	splitting	charged
attraction	operates	lead
electrons	competes	show

Scattering experiments, in which positively charged particles are shot at atomic nuclei, show that the inverse-square coulomb force holds down to dimensions of about 10^{-14} m, the size of the very small, positively .... nuclei of atoms. Indeed, the coulomb force .... between the protons *within* a nucleus. The electric repulsion between protons .... with the strong nuclear force of .... among protons and neutrons. In the heavier atoms, in which there are many protons, the coulomb repulsion is .... for instabilities which can .... to the ejection of helium nuclei in α decay or the .... of the nucleus in nuclear fission. Furthermore, indirect experiments involving the interaction of .... and muons with atomic nuclei .... that Coulomb's law is valid down to distances of about 10^{-16} m.

D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. The familiar gravitational force is important only when the mass of one of two interacting objects is comparable to that of a planet.

b. The electromagnetic forces dominate all interactions of systems from the size of atoms to that of planets.

c. With the exception of the force due to gravity, all the forces of ordinary experience–the restoring force of a stretched string, the normal force of a floor acting upward on a person, the force between colliding automobiles–indeed, all the forces acting between the atomic nucleus and its surrounding electrons, or between atoms in molecules, are ultimately electromagnetic in origin.

d. All the known forces in physics arise from four fundamental interactions: the strong nuclear force, the electromagnetic force, the weak interaction force, and the gravitational force.

e. This leaves the *electromagnetic force.*

f. The nuclear and the weak interaction forces are of importance only within the atomic nucleus, in certain collisions between nuclei, and in the decays of unstable elementary particles.

1	2	3	4	5	6

Section Two: Further Reading

Electric Charge

The distinctively new concept introduced in electromagnetism is that of *electric charge.* We know that when any two dissimilar nonmetallic objects are brought into intimate contact with one another–for example, by rubbing glass with silk–and then separated from one another, they show a mutual attraction, exceeding by far their gravitational attraction. Such objects are said to be electrically charged, and the presence of electric charge on each object is responsible for their interaction by an electric force. The reader is assumed to be familiar with this effect and the many qualitative experiments which establish the following fundamental facts concerning these electric interactions: *(a)* There exist *two kinds of charge, (b) like charges repel,* and *(c) unlike charges attract* (Figure 2-3).

In this section we shall deal with electrostatics, the science of electric charges at rest. Besides repelling or attracting by the electrical force, charges in motion interact by the so-called magnetic force. Here we shall deal only with situations in which the charges' velocities are so much smaller than the speed of light (3.0×10^8 m/s) that the magnetic force between the charges is negligible compared with the electric force between them.

All electrical phenomena arise from the fact that the fundamental elementary particles of physics may have the property of electric charge. Thus, the electron has a negative charge, the proton a positive charge, and the neutron a zero charge. The use of the algebraic signs + and – to denote the two kinds of charge is appropriate, since combining equal amounts (to be defined precisely below) of positive and negative charges results in a zero electric force acting on an object.

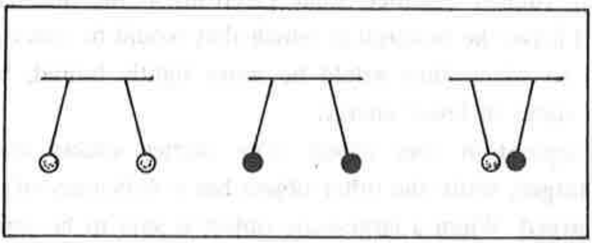


Figure 2-3. Charged Objects Suspended From Insulating Strings. Like charges repel, unlike charges attract.

As we know, the nucleus of an atom, consisting of protons and neutrons bound together within a volume whose length dimensions are never much greater than 10^{-14} m, is surrounded by electrons which are bound to it. An atom is electrically neutral as a whole when the number of electrons surrounding the nucleus equals the number of protons in the nucleus.

Atoms are closely packed in solids, their nuclei being separated from one another by distances of the order of 10^{-10} m. In *conductors,* of which metals are examples, most of the electrons are bound to and remain with their parent nuclei, but approximately one electron per atom may be a *free electron.* A free (or conduction) electron, although bound to the conductor, may wander throughout the interior of the conducting material and can easily be displaced within the conductor by external electric forces. In *insulating,* or *dielectric,* materials on the other hand, *all* atomic electrons are *bound,* to a greater or lesser degree, to their parent nuclei. Electrons are removed from or added to an insulating material only with the expenditure of energy. Examples of common conductors are metals, liquids having dissociated ions (electrolytes), the earth, and the human body. Good insulators are very often transparent materials: plastics, glass, and a vacuum, which is a perfect insulator. The best electrical conductors are better than the worst conductors (or best insulators) by enormous factors, up to 10^{20}.

Lying between these extremes are the so-called semiconductors, whose conductivity is intermediate between conductors and insulators. Examples of semiconductors are germanium and silicon. In semiconductors only a very small fraction of the electrons are free. The number of conduction electrons in a semiconductor may be changed by heating the material, by shining light on it, or by applying a very strong external electric field.

Electrostatic effects may be understood on the basis of the atomic model and of the properties of conductors and dielectrics. When two unlike dielectrics are rubbed together, some electrons at the interface between the materials will leave the material to which they would be less tightly bound for the material to which they would be more tightly bound, because systems always go to states of lower energy.

Upon separation one object now carries excess electrons and is negatively charged, while the other object has a deficiency of electrons and is positively charged. When a large-scale object is said to be positively charged, its electrical neutrality has been disturbed by its having lost electrons; similarly, a negatively charged object is an object with excess electrons. 'Charging' an object consists simply of adding or subtracting electrons from it. When one type of charge is produced on an ordinary object, the other type must appear in equal amounts on a second object. The charging of any large-scale body results from the separation of charged particles (see Figure 2-4). Since a charged body has acquired or lost electrons, we sometimes speak of the charge *on* a body. Of course the body acquires (or loses) not only the charge of electrons added to (or removed from) it but also the mass of the added (or removed) electrons. However, the additional mass is usually so trivial as to be negligible.

It is not proper to speak of the charge *on* an electron (or on any other elementary particle for that matter). Electric charge is not something that can be added to or removed from an electron. An electron without charge does not exist. Since electric charge is, like mass, an intrinsic property of an electron, we speak of the electric charge *of* an electron.

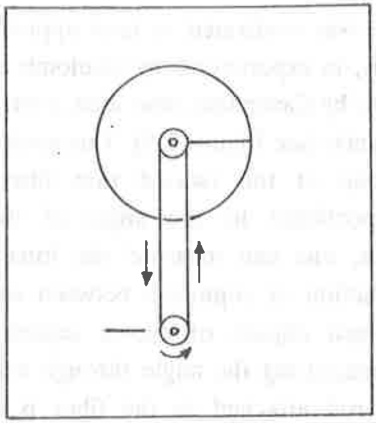


Figure 2-4. Schematic Diagram for a Van de Graaff Generator, a Device for Separating Charge. The moving belt continuously carries charge from sharp points near it at the lower roller to points on the interior of a spherical conductor.

Here we establish the quantitative aspects of the electric interaction between charges. The electric force is often referred to as the coulomb force, named after C. A. de Coulomb (1736–1806) who in 1785 found the electric force to vary as the inverse square of the separation distance.

We shall consider point-charges. A point-charge is a group of one *or more* elementary charged particles confined to a region of space which is small compared with any other dimensions with which we might be dealing, such as the separation distance between two point-charges. A single elementary particle best exemplifies the concept of point-charge, but even here the charge has finite size. The stability of a charged particle of nonzero size against the strong mutual repulsion of its parts is not understood on the basis of present-day fundamental physical theory. We must simply say, for example, that the charge of an electron is confined to a very small volume, leaving the question of what holds it together as an important one not yet answered.

The electric force between point-charges at rest is found to lie along the line connecting them. Thus, the coulomb force is a *central force.* Indeed, it could not be otherwise, for between two points at rest in empty isotropic space the only unique direction is the line between them.

The Coulomb force varies *inversely as the square of the distance r* between two point charges:

$$F \propto \frac{1}{r^2}$$

This was confirmed, at least approximately, in experiments by Coulomb and, later, by Cavendish, who used a torsion balance (see Figure 2-5). The restoring torque of the twisted thin fiber is proportional to the angle of twist. Thus, one can measure the force of attraction or repulsion between small charged objects of known separation by measuring the angle through which the rod attached to the fiber is displaced. Such experiments with charged objects are similar to the Cavendish experiment, in which the gravitational force between two small objects is measured. Although experiments with a torsion balance can establish that the exponent of r in $F \propto 1/r^n$ is 2 to within a few percent, other experiments show by indirect means that the exponent is precisely 2 (to within a few parts in 10^9).

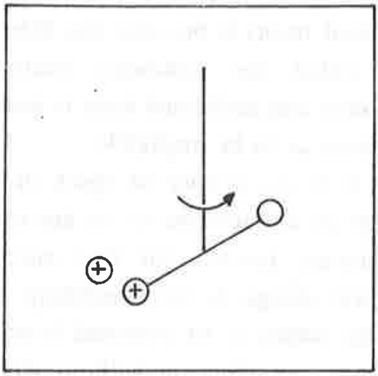


Figure 2-5. Cavendish Torsion Balance for Measuring the Variation in the Coulomb Force With the Distance Between Two Charged Objects.

Weidner, R. T., & Sells, R. L. (1973: pp. 313-316).

Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The mutual attraction between two unlike charged objects is greater than their gravitational attraction.

.... 2. Electrostatics is limited to the study of attraction and repulsion between two nonmetalic objects.

.... 3. The fundamental elementary particles of the electron, the proton and the neutron, share the common characteristic of having electric charge.

.... 4. In conductors, all of the electrons are bound to their parent nuclei.

.... 5. The state of the atomic electrons being bound or free from their parent muclei determines the nature of materials as being conductive or nonconductive.

.... 6. The number of conduction electrons in semiconductor materials is intrinsically fixed.

.... 7. The atomic model is used to explain electrostatic effects.

.... 8. The act of adding or removing electrons from an object is referred to as 'charging'.

.... 9. Charging an object effects both the amount and the mass of electrons.

.... 10. The present fundamental physical theory has explained the stability of a charged particle against the repulsion of its parts.

B. Choose a, b, c, or d which best completes each item.

1. The state of the atomic electrons being bound or free from the parent nuclei will result in the existence of all of the following except ....

a. conductors
c. insulators
b. semiconductors
d. semi-insulators

2. The statement that the fundamental elementary particles of physics are characterized by the electric charge applies to all of the following except that .... charge.

a. the electron has a negative
c. the atom has a neutral
b. the proton has a positive
d. the neutron has a zero

3. One of the basic facts about the electric interactions is that .... each other.

a. dissimilar electric charges repel
b. similar electric charges attract
c. dissimilar electric charges attract
d. similar electric charges do not repel

4. According to the science of electric charges at rest, if two dissimilar insulators are rubbed together, ...

a. all atomic electrons will remain bound to their parent nuclei
b. some electrons from a system of higher energy will move to a system of lower energy
c. all atomic electrons will wander throughout the interior of the conductor
d. some electrons from a system of lower energy will move to a system of higher energy

5. There is a connection between the amount of ....

a. electrons in an object and its being negatively or positively charged
b. electrons and the size of the object
c. mass of an object and its being negatively or positively charged
d. free electrons and the size of the parent nucleus

6. One of the differences between a charged body and an electron is that ....

a. in the case of former we can talk about *of* a body but in the latter about *on* an electron

b. the electrical neutrality of the former cannot be disturbed but that of the latter can be

c. the former has the same characteristics as the mass but the latter does not

d. whereas the electric charge is an essential characteristic of the latter, the former has acquired it

C. Write the answers to the following questions.

1. What makes an object to become electrically charged?
2. What does a free electron mean?
3. What is meant by an electric charge?
4. What is the role of parent nuclei in dielectric materials?
5. How can electrons be removed from an insulating material?
6. What happens when two unlike dielectrics are rubbed together?
7. What does the expression of 'the electric charge *of* an electron' signify?
8. What does a point-charge mean?
9. What does a central force refer to?
10. How does the distance r between two point-charges affect the Coulomb force?

❂ ❂ ❂

Section Three: Translation Activities

A. Translate the following passage into Persian.

Gravitational and Electric Forces

The gravitational and electric forces are similar in several respects: Both are *central, conservative, inverse-square forces.* Therefore, many of the concepts developed for gravitation–the gravitational field, the gravitational potential energy, the energetics of particles interacting under the gravitational force–are equally appliable to the electric force. But there are also emphatic differences. For one thing, there are two types of electric charge, but only one type of gravitational charge (or gravitational mass). Electric charges may attract or repel; gravitational charges attract only. Another important difference is in the relative magnitudes of the electric and gravitational interactions. The electric force is immensely larger than the gravitational force; for example between an electron and a proton the electric attraction is

10^{39} times greater than the gravitational attraction.

At the atomic level the gravitational force is altogether trivial compared with the electric force. On the other hand, because the negative and positive charges of the elementary particles (the constituents of ordinary objects) are equal in magnitude and the electric force between them so great, ordinary objects are generally electrically neutral. Thus, the electric force, operating internally at the atomic scale, is not manifest for large-scale objects whereas the gravitational force is.

B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. angle of twist ....
2. atomic scale ....
3. conducting shell ....
4. conservative force ....
5. Coulomb force ....
6. dielectric ....
7. dissociated ions ....
8. electric field ....
9. electric flux ....
10. electric repulsion ....
11. electrically neutral ....
12. electroscope ....
13. electrostatic equilibrium ....
14. germanium ....
15. gravitational attraction ....
16. hollow conductor ....
17. inverse-square variation ....
18. isotropic space ....
19. magnetic force ....
20. net charge ....
21. nonzero size ....
22. parent nuclei ....
23. point-charge ....
24. positive charge ....
25. restoring torque ....
26. semiconductor ....
27. spherically symmetric ....
28. torsion balance ....

Unit 3

Section One: Reading Comprehension

Magnetism

Magnets were known by the ancients, and much of our qualitative terminology concerning magnetic fields is colored by this fact. In particular, we often speak of magnetic fields in terms of bar magnets, since this is the way the fields were first studied. For example, we know that the poles of a bar magnet experience forces when placed in a magnetic field. If a bar magnet is suspended by a delicate fiber, as shown in Figure 3-1, a particular end of the magnet will always point approximately north on the earth, provided no other magnetic objects are nearby. This end of the magnet is called the *north pole of* of the magnet. The other end is the *south pole.* A device such as this is nothing more than a simple compass.

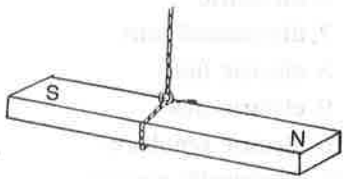


Figure 3-1. The North Pole of a Magnet Is Defined to Be the Pole That Points North When the Magnet Is Freely Suspended.

Further studies with bar magnets show that the north poles of two magnets repel each other. The south pole of a magnet is always attracted by the north pole of another magnet. If one tries to break off the north pole from a simple bar magnet, the effort proves unsuccessful. The broken magnet becomes two new bar magnets, each having a north and a south pole. These are qualitative features with which we are all familiar.

Magnetic fields are easily plotted by means of compass needles, small bar magnets. The direction in which the compass needle points is taken to be the direction of the magnetic field. We can therefore determine the direction of the magnetic field at a point by observing the orientation of a small compass needle placed at the point. This fact is used in Figure 3-2 to plot the magnetic field in the vicinity of bar magnet. The magnetic field lines are drawn in such a way that a compass needle placed on the line will align itself tangentially to the line. Typical magnetic fields are shown in Figure 3-3. Notice that the field lines emerge from north poles and enter south poles. Why is this always true? As we see from the Figure, the earth acts like a huge magnet with the magnet's north pole being near the position of the earth's south pole. *The* *earth's geographic north pole is near its magnetic south pole.*

An important step in the understanding of the nature of magnetic fields occurred in 1820 when Hans Christian Oersted discovered that currents in wires produce magnetic fields. This fact is easily demonstrated by the experiment illustrated schematically in Figure 3-4a. If no current flows in the wire, the compass needles line up parallel to each other, all pointing north. However, when a current flows in the wire, the needles line up as indicated. Experiments such as this show that the current-carrying wire has a magnetic field about it similar to that shown in Figure 3-4b. In this, as well as in later diagrams, the symbol indicates an arrow .coming toward the reader, and x represents an arrow going away from the reader. The symbols are meant to suggest the tip and tail of the arrow.

A simple rule for remembering the direction of the magnetic field lines about a wire is the *right-hand rule.* This rule states that if one grasps the wire with the right hand in such a way that the thumb points in the direction of the current, the fingers will circle the wire in the same sense as do the field lines. This rule is illustrated in Figure 3-5. Notice that it is very similar to the right-hand rule for the direction assigned to torques and rotations.

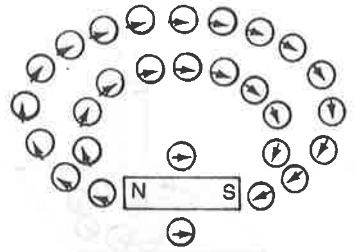


Figure 3-2. A Compass Needle Points in the Direction of the Magnetic Field.

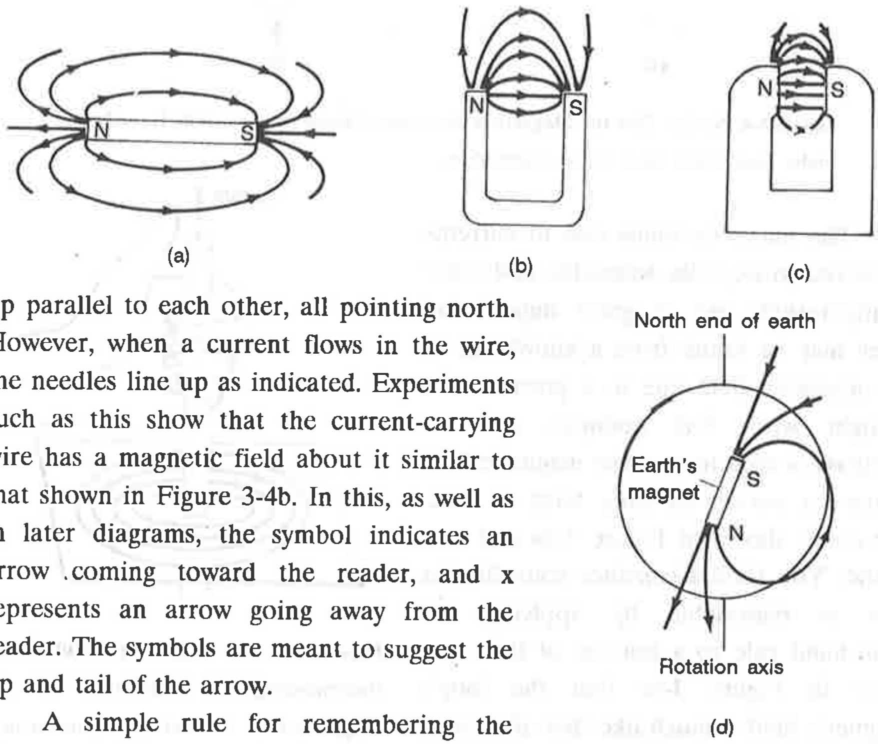


Figure 3-3. Using the Fact That a Compass Needle Should Line up Along the Field Lines,You Should Be Able to Show That the Lines Drawn Are Reasonable.

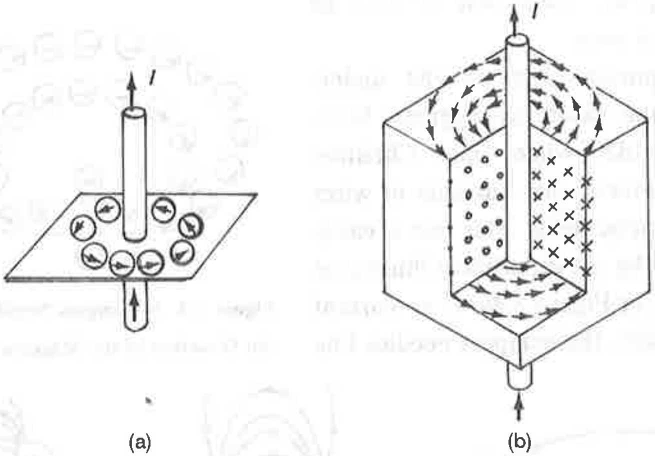


Figure 3-4. Notice That the Magnetic Field Lines Caused by a Current Have No Ends: They Circle Back Upon Themselves.

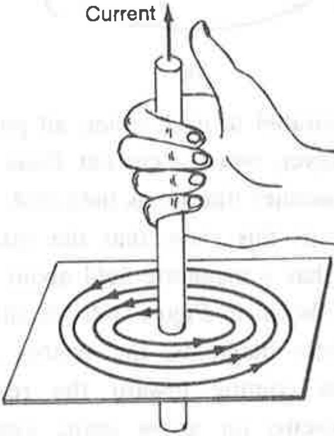


Figure 3-5. The Right-Hand Rule for Remembering the Direction of a Magnetic Field Caused by a Current in a Wire.

The magnetic fields due to currents in curved wires, coils, solenoids, and other configurations are of great importance. They may be found from a knowledge of the magnetic field due to a portion of a straight wire. For example, when a compass is used to plot the magnetic field around a current-carrying loop of wire, the result shown in Figure 3-6a and b is found. You should convince yourself that this is reasonable by applying the right-hand rule to a portion of the loop. Note in Figure 3-6c that the loop's magnetic field is much like that of a short, fat bar magnet. In that sense, the current loop can be considered to have a north and south pole. We shall see later that this is one aspect of a very important and far-reaching similarity between bar magnets and current loops. It is a simple matter to show that a wire carrying a current through a magnetic field experiences a force. For example, a schematic diagram of such an experiment is shown in Figure 3-7. There we see a wire carrying a current *I* through a magnetic field furnished by a magnet. The field is directed from right to left

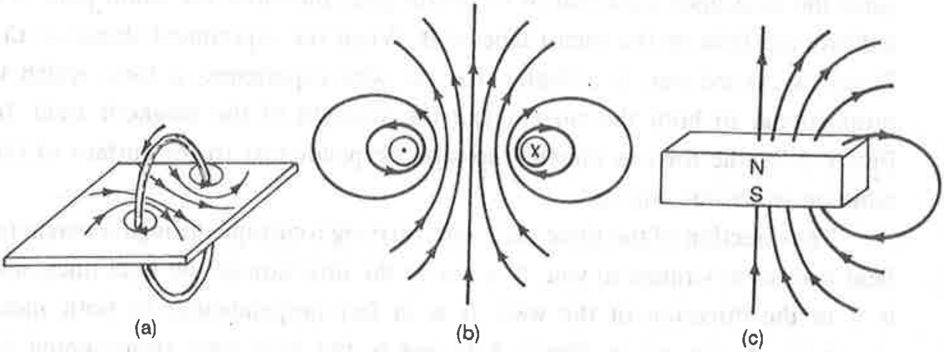


Figure 3-6. The Current-Carrying Loop Shown in (a) and (b) Has a Magnetic Field Much Like That of the Short Bar Magnet Shown in (c).

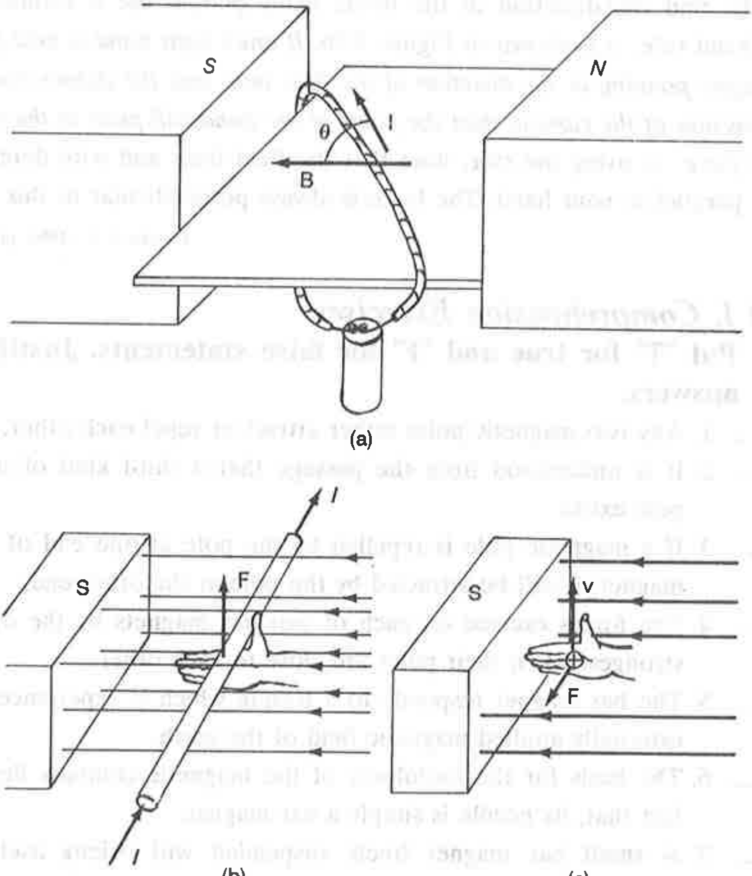


Figure 3-7. A Simple Right-Hand Rule for Remembering the Direction of F.

since the field lines come out of the north pole and enter the south pole. We indicate the field by the vector labeled **B**. When the experiment shown in the Figure is carried out, it is found that the wire experiences a force which is proportional to both the current and the strength of the magnetic field. In Figure 3-7a, the force is directed upward, perpendicular to the surface of the table on which the wire lies.

The direction of the force on a wire carrying a current through a magnetic field may seem strange to you. It is not in the direction of the field lines, nor is it in the direction of the wire. It is in fact perpendicular to both these directions. As we see in Figure 3-7a and b, the field lines (represented by B)and the current I define a plane–the plane of the tabletop in Figure 3-7a. The force on the wire is always perpendicular to the plane defined by **B** and **I**.

To find the direction of the force, many people use a variant of the right-hand rule. It is shown in Figure 3-7b. *If one's right hand is held flat with the fingers pointing in the direction of the field lines and the thumb pointing in the direction of the current, then the palm of the hand will push in the direction of the force.* In using the rule, note that the field lines and wire determine a plane parallel to your hand. The force is always perpendicular to this plane.

Bueche, F. J. (1986: pp. 441-444).

Part I. Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. Any two magnetic poles either attract or repel each other.

.... 2. It is understood from the passage that a third kind of magnetic pole exists.

.... 3. If a magnetic pole is repelled by the pole at one end of another magnet, it will be attracted by the pole at the other end.

.... 4. The forces exerted on each of two bar magnets by the other are strongest when their poles are close to each other.

.... 5. The bar magnet responds to a torque which it experiences in the externally applied magnetic field of the earth.

.... 6. The basis for the usefulness of the magnetic compass lies in the fact that, its needle is simply a bar magnet.

.... 7. A small bar magnet freely suspended will orient itself in an approximately north-south direction regardless of the presence of other nearby magnets.

.... 8. The direction of the force on a wire carrying a current through a magnetic field is at an angle of 90° to both the direction of the field lines and the direction of the wire.

B. Choose a, b, c, or d which best completes each item.

1. The main idea of the first paragraph is that ....
   a. the north pole of a magnet and the earth point in the same direction
   b. a magnet has two different poles with concentrated magnetism
   c. a simple compass works on the principle of magnetism
   d. the idea of magnetic field was known to man for centuries
2. If a bar magnet is broken into two pieces, ...
   a. the resultant pieces will attract each other
   b. only one of the magnets will have the qualitative features of a magnet
   c. the resultant pieces, each will have a north and a south pole
   d. we will have two magnets one with a north and the other with a south pole
3. The magnetic field lines can be plotted by ....
   a. observing the orientation of a small compass needle at a particular place
   b. studying the relationship of the earth's geographical and magnetic poles
   c. observing the direction of the emerging lines from north poles and entering south poles
   d. determining the possible tangents of the field lines to the magnetic field
4. The magnetic fields of current loops can be explained by applying the right-hand rule to ....
   a. a portion of straight wire
   b. a simple bar magnet
   c. a current-carrying wire
   d. a small compass needle
5. The force experienced in a wire carrying a current through a magnetic field has a direct relationship with ....
   a. the intensity of the current
   b. the length of field lines
   c. the strength of the magnetic field
   d. the current and the strength of the magnetic field

6. If a current flows in a wire, ...
   a. the resultant magnetic field lines will begin at the south pole and end at the north pole
   b. the compass needles in the vicinity will all point to the same direction
   c. the application of the right-hand rule will show the field lines
   d. the resultant magnetic field lines will be rotating around the wire

C. Answer the following questions orally.

1. What is the right-hand rule?
2. What is the direction of the magnetic field lines?
3. What is the basic similarity between current loops and bar magnets?
4. Which poles of different magnets will repel each other?
5. What changes take place in the compass needles when a current flows in the wire?
6. How can it be demonstrated that currents in wires produce magnetic fields?
7. Which poles of different magnets will attract each other?
8. How is the direction of the force on a current found?
9. How can the magnetic fields caused by currents be found in coils?

Part II. Language Practice

A. Choose a, b, c, or d which best completes each item.

1. Magnetic flux density is another .... for magnetic induction.
   a. fame — c. reputation
   b. name — d. designation
2. The .... of the magnetomotive force acting in a magnetic circuit to the magnetic flux is called reluctance.
   a. relation — c. relative
   b. rate — d. ratio
3. A magnet .... to have its magnetism concentrated at two points termed the poles.
   a. looks — c. appears
   b. shows — d. figures
4. The product of the magnetic pole .... and the length of the magnet is called magnetic moment.
   a. vigor — c. sinew
   b. intensity — d. strength
5. The ratio of the magnetic moment of an atom or nucleus to its .... momentum is referred to as gyromagnetic.

a. crooked
c. angular
b. sharp
d. forked

6. The metals iron, cobalt, nickel, and certain alloys which are .... more magnetic than any other known substances are said to be ferromagnetic.

a. hugely
c. colossally
b. gigantically
d. vastly

B. Fill in the blanks with the appropriate form of the words given.

1. Attract

a. Whether clothes are .... or not seems to depend partly on fashion, partly on social considerations, and partly on personal taste.

b. Probably some of you possess a piece of iron which can .... small metal objects (like pins and needles) towards itself.

c. When a thing falls to the ground, it is because of the earth's ....

d. Her room was decorated so .... that even older people were delighted with it.

2. Illustrate

a. The mechanism of a blood cell provides an excellent .... of the point in question.

b. He has .... his classification by giving typical case histories.

c. The scientist provided .... examples to clear the abstract and general points.

3. Demonstrate

a. The truth of a scientific theory is .... by the evidence which supports the theory.

b. A science teacher gives a .... of an experiment when he shows his students how to do it by performing it in front of them.

c. The best way of teaching practical skills is to present them ....

d. Scientists usually can be easily recognized by their .... behavior.

4. Consider

a. Plans to expand the industry must be .... in relation to the trained workers available.

b. These are important .... and I am glad you brought them to my attention.

c. For many years they were able to produce and sell their goods more cheaply than other nations and this gave them a .... advantage in world trade.

d. Production has .... improved during the last three years.

5. Act

a. Today we will study the .... of oxygen on iron and other metals.

b. The brakes would not ...., so there was an accident.

c. A boy with an .... brain will be more successful than a dull boy.

d. The scientist participated in the experiment ....

6. Possess

a. The local authorities .... some land on the other side of the university.

b. Do not neglect the possibility that his .... manner might have led everybody to dislike him.

c. When the country was divided, he lost his ....

d. The president of the company treated the strictly confidential information ....

C. Fill in the blanks with the following words.

individual	permanent	molecule	values
resultant	intrinsic	between	total
electron	angular	motion	atom

The close relation between magnetic moment and .... momentum is of great importance in atomic theories of magnetism, because on quantum theory the angular momentum of a/an .... in an atom, which is a constant of the motion, can only have discrete .... The electron possesses angular momentum not only in respect of its orbital .... round the nucleus, but also in respect of its .... rotation (spin) about its own axis. The resultant angular momentum of a/an .... is the vector sum of the individual angular momenta of its electrons, and the .... magnetic moment is a similar vector sum of the .... magnetic moments of the electrons. Because of the linear relation .... the two, an atom, ion, or molecule will have no resultant .... magnetic moment if the total angular momentum is zero. If the .... angular momentum is not zero, the atom, ion or .... will have a permanent magnetic dipole moment.

D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

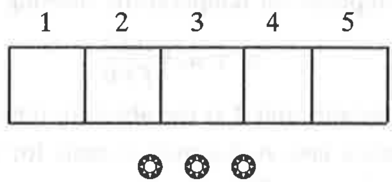
a. Presumably these charges are moving in closed paths, the nature of which will be determined by the resultant structure of the atomic and molecular systems.

b. Such permanently circulating currents are often called **American currents** since Ampere first postulated their existence in order to account for the magnetic properties of matter.

c. Previously, we assumed that atoms and molecules were composed of positive and negative charges and were, on the whole, electrically neutral.

d. From a great distance, these moving charges will appear as current whirls or magnetic dipoles.

e. We now extend this picture by assuming that at least some of these charges are not at rest but are in continuous motion.



Section Two: Further Reading

Magnetism

Paramagnetism and Diamagnetism

In most substances, with some notable exceptions the magnetic permeability depends very little on the field strength so that taking it constant, introduces no appreciable error. Unlike the relative capacitivity, the relative permeability may be either greater or less than 1. Substances in which it is greater are called paramagnetic, and those in which it is less diamagnetic. Let us consider the forces acting on such bodies when placed in the field of a fixed circuit carrying a constant current. If any infinitesimal displacement or rotation of the circuit will increase the flux through it, then there is a force or torque trying to produce this motion. If there are any bodies in the field of this circuit whose displacement or rotation will increase the flux through it then, by Newton's law of reaction, there will be corresponding forces or torques acting on these bodies. The magnetic induction or flux density and the permeability are related in magnetic circuits in exactly the same way as the current density and the electric conductivity in electric circuits. If the permeability of any element in the magnetic field of an electric current is increased or decreased, the reluctance of the magnetic circuit is decreased or increased, respectively. As we have seen, these are forces acting to increase the flux and hence to decrease the reluctance. Thus, in an inhomogeneous field, there is a tendency for bodies that are more paramagnetic or less diamagnetic than the ambient medium to move toward the more intense parts of the field, and vice versa. If a paramagnetic or diamagnetic body of elongated shape is placed in a uniform field, there is a torque tending to set its axis parallel to the field.

Quantum mechanics gives a theoretical basis for the empirical fact that the permeability of diamagnetic bodies is usually independent of temperature. For weakly paramagnetic substances, the permeability is often independent of temperature. In strongly paramagnetic, but not ferromagnetic, substances, the permeability usually depends on temperature, obeying the equation

$$\mu = \mu_v + \frac{\mu_v C}{T+\theta} \tag{3-1}$$

where C and θ are constants and T is the absolute temperature. This empirical relation is called Curie's law. A theoretical basis for it is found in quantum mechanics. For gases, θ is usually zero.

Magnetic Susceptibility

It is often convenient to use a new quantity magnetic susceptibility defined, in an isotropic medium, in terms of the equations

$$\kappa H = M = B\left(\frac{1}{\mu_v} - \frac{1}{\mu}\right) \tag{3-2}$$

Thus susceptibility and permeability are related by the equation

$$\kappa = \mu_v^{-1}(\mu - \mu_v) = K_m - 1 \tag{3-3}$$

When a substance is placed in a magnetic field, its energy is decreased if it is paramagnetic and increased if it is diamagnetic. The change is given by

$$\Delta W = \frac{\mu_v H^2}{2} - \frac{B^2}{2\mu} = \frac{(\mu_v - \mu) H^2}{2} = -\frac{\mu_v}{2} \kappa H^2 \tag{3-4}$$

We notice that, for paramagnetic bodies, κ is positive; for diamagnetic bodies, it is negative. Curie's law may be expressed more simply in terms of the susceptibility by the empirical equation

$$\kappa = \frac{C}{T+\theta} \tag{3-5}$$

A theoretical basis for this equation has also been worked out.

Magnetic Properties of Crystals

Many substances, especially crystals, possess different magnetic properties in different directions. It is even possible with some materials, such as graphite, to prepare specimens that are paramagnetic in one direction and diamagnetic in another. In such cases, it is found however that for any given orientation the magnetic induction ***B*** is proportional to the field intensity ***H*** and makes a constant angle α with it. This relation is similar therefore to that connecting the electric displacement ***D*** and the electric field intensity ***E*** in a crystal and can be formulated by writing a set of equations. We find, therefore, that the components of ***B*** and ***H*** are connected by the relations

$$\begin{aligned} B_x &= \mu_{11}H_x+\mu_{21}H_y+\mu_{31}H_s \\ B_y &= \mu_{12}H_x+\mu_{22}H_y+\mu_{32}H_s \\ B_s &= \mu_{13}H_x+\mu_{23}H_y+\mu_{33}H_s \end{aligned} \tag{3-6}$$

where $\mu_{12} = \mu_{21},\ \mu_{13} = \mu_{31},\ \mu_{23} = \mu_{32}$ (3-7)

Thus ***B*** and ***H*** are now connected by a quantity having nine components of which six are different. The permeability, formerly a simple ratio, has become a symmetrical tensor. By a suitable orientation of axes, (3-6) may be written as

$$B_x = \mu_1 H_x,\quad B_y = \mu_2 H_y,\quad B_s = \mu_3 H_s \tag{3-8}$$

When (3-8) holds, the coordinate axes are said to lie along the magnetic axes of the crystal.

By means of (3-2), we see that the corresponding equation connecting the magnetic susceptibility and intensity of magnetization are

$$M_x = \kappa_1 H_x,\quad M_y = \kappa_2 H_y,\quad M_s = \kappa_3 H_s \tag{3-9}$$

where $\mu_v\kappa_1=\mu_1-\mu_v$, etc. By rotation of coordinates, we can get a set of equations, connecting ***M*** and ***H*** in a crystal, analogous to (3-6) and involving a tensor magnetic susceptibility.

The Nature of Permanent Magnetism

We have considered the energy in a magnetic field as essentially kinetic, it being associated with the motion of electric charges. As the magnetic fields produced by permanent magnets appear in every respect to be identical with those produced by electric currents, it is natural to seek a similar origin for them. The nature of permanent magnetism is revealed by a group of phenomena known as the gyromagnetic effects. Since no electricity is entering or leaving a permanent magnet, any motion of electricity therein must be circulatory and this circulation or spin must be about axes that are oriented, on the average, in a definite direction to produce a definite external field. If, the electrical carriers possess mechanical inertia, then when circulating in closed paths or spinning, they possess angular momentum and therefore are subject to gyroscopic forces. Such forces were predicted by Maxwell but could not be detected with the experimental technique of his day. Two effects immediately suggest themselves. The first of these is magnetization by rotation. A well-known fact in mechanics is that when the supporting system of a gyroscope is rotated and its axis ***a*** is free to turn only in the plane common to it and the axis ***b*** of rotation of the system, then *a* tends to set itself parallel to *b*.

Thus, if an unmagnetized body possessed circulating or spinning electricity with axes oriented at random, a rotation of this body should produce an alignment of these axes with the axis of rotation, and the body should become magnetized. Such effects have been detected and measured by Barnett in ferromagnetic substances. The second effect is the converse of the first, rotation by magnetization. From the law of conservation of angular momentum, if the random axes of rotation are aligned by a magnetic field, then the body as a whole must rotate in the reverse direction to keep the resultant angular momentum zero. This effect was first measured by Einstein and De Haas and has since been done with greater precision by other experimenters. Both effects show that there is a rotation of negative electricity in ferromagnetic bodies and that the average magnetic moment of the individual gyroscopes is slightly greater than that of a spinning electron. The excess is supposed to be due to an 'orbital' motion of the electrons. Thus, we see that the magnetic fields of permanent magnets are not different from those already studied.

Smythe, W. R. (1989: pp. 349-351, 354-355).

Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The field strength is a determining factor of the magnetic permeability.

.... 2. The gyromagnetic effects explain the characteristics of permanent magnetism.

.... 3. An increase in the flux will result in a decrease in the reluctance.

.... 4. Magnetic properties of all substances are aligned in the same direction.

.... 5. There is a close relationship between the permeability of diamagnetic bodies and temperature.

.... 6. An increase in the permeability of an element in the magnetic field will result in a decrease of the magnetic circuit.

.... 7. The energy in a magnetic field is essentially present by virtue of the motion of electric charges.

.... 8. The average magnetic moment of each gyroscope is significantly more than that of a spinning electron.

.... 9. Newton's law of reaction is used to account for the forces acting on bodies placed in the field of a fixed circuit.

B. Choose a, b, c, or d which best completes each item.

1. Substances in which relative permeability is greater than 1 are referred to as ....
   a. diamagnetic
   b. ferromagnetic
   c. paramagnetic
   d. ferrimagnetic.
2. The relationship between flux density and permeability in magnetic circuits is similar to that of ....
   a. current density and the electric conductivity in electric circuits
   b. the infinitesimal displacement of the circuit and the resultant decrease in the flux through it
   c. the relative permeability of the magnet and the field strength
   d. torque trying to produce a motion and the fixed circuit carrying an alternating current
3. The phenomenon of diamagnetism occurs in all substances, although the resulting diamagnetism is ....
   a. often the outcome of the application of an external magnetic field
   b. characteristic of substances with small negative magnetic susceptibility
   c. due to a change in the orbital motion of the electrons in the atoms
   d. often masked by the much greater effects due to ferromagnetism
4. The ratio of the magnetic flux density in a body to the external magnetic field strength which induces it is called magnetic ....
   a. variation
   b. susceptibility
   c. declination
   d. permeability
5. Paramagnetism occurs in those substances of which individual atoms, ions, or molecules possess ....
   a. some kind of thermal agitation within the substance
   b. a permanent magnetic dipole moment

c. lower energy than the antiparallel position

d. a net magnetization parallel to the field

6. The presence of either a permanent magnet or a circuit carrying an electric current, will result in magnetic ....

a. force c. field

b. flux d. potential

7. The ratio of the intensity of magnetization produced in a substance to the strength of the magnetic field to which it is subjected is called magnetic ....

a. permeability c. moment

b. monopole d. susceptibility

C. Write the answers to the following questions.

1. What is the first gyromagnetic effect?
2. How does the second gyromagnetic effect work?
3. Which substance is diamagnetic in one direction and paramagnetic in another?
4. How are permeability and susceptibility related to each other?
5. What is the similarity between the magnetic fields produced by permanent magnets and electric currents?
6. What is meant by magnetization by rotation?
7. What kind of electricity do ferromagnetic bodies have?
8. What was the contribution of Barnett to the study of uniform magnetization?
9. Why is the electricity of a permanent magnet circulatory?
10. Why are the electrical carriers subject to gyroscopic forces?

○ ○ ○

Section Three: Translation Activities

A. Translate the following passage into Persian.

Magnetic Force and Magnetic Field

Magnetism and electricity are so closely linked that we will soon define the magnetic field in terms of the way in which it affects electric charges. But the connections between electricity and magnetism do *not* lie in the similarities between the behavior of electrically charged objects and the behavior of magnets. Electric and magnetic phenomena are distinct. In particular, Gilbert showed in 1600 that magnetic compasses do not interact with electrically charged rods in experiments where there was no relative motion. The links between electricity and magnetism are both more and more profound.

The first of these links is this: An electric charge experiences a force when it is *moving* in a magnetic field. This force is called the magnetic force. The motion is absolutely essential.

When there is no electric field in a region, no force is exerted on a stationary test charge in the region. However, experiment shows that a force is exerted on the test charge if the charge is moving in the vicinity of a magnet. *It is this magnetic force which gives evidence of the presence of a magnetic field at the location of the test charge.* Experiments shows that, other things being equal, the magnitude of this force is proportional to the speed of the test charge.

More specifically, we use the magnetic force to define a vector called the **magnetic field** β. The 'official' name of the quantity β is the magnetic *induction*; strictly speaking, the word 'field' signifies the entire array of vectors β everywhere in space. But it is common practice to call the vector β at any particular location the *magnetic field,* just as it is common practice to call the vector ε at any particular location the electric field rather than using its 'official' name *electric field intensity.*

B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. angular momentum ....
2. bar magnet ....
3. capacitivity ....
4. compass needle ....
5. current loop ....
6. declination ....
7. diamagnetism ....
8. electric field intensity ....
9. ferrimagnetic ....
10. ferromagnetic ....
11. field lines ....
12. flux density ....
13. gyromagnetic effect ....

14. gyroscope ....
15. inhomogeneous field ....
16. isotropic medium ....
17. law of reaction ....
18. magnetic dipole moment ....
19. magnetic field ....
20. magnetic force ....
21. magnetic induction ....
22. magnetic susceptibility ....
23. mechanical inertia ....
24. paramagnetism ....
25. permeability ....
26. precession ....
27. reluctance ....
28. right-hand rule ....
29. spheroid ....
30. symmetrical tensor ....
31. vector sum ....

Unit 4

Section One: Reading Comprehension

Optics

The Rectilinear Propagation of Light

The rectilinear propagation of light is the technical terminology applied to the principle that "light travels in straight lines." The fact that objects can be made to cast fairly sharp shadows may be considered a good demonstration of this principle. Another illustration is found in the pinhole camera. In this simple and inexpensive device the image of a stationary object is formed on a photographic film or plate by light passing through a small opening, as diagramed in Figure 4-1. In this Figure the object is an ornamental light bulb emitting white light. To see how an image is formed, consider the rays of light emanating from a single point *a* near the top of the bulb. Of the many rays of light radiating in many directions the ray that travels in the exact direction of the hole passes through to the point *a′* near the bottom of the image screen. Similarly, a ray leaving *b* near the bottom of the bulb and passing through the hole will arrive at *b′*, near the top of the image screen. Thus it can be seen how an inverted image of the entire bulb is formed.

If the image screen is moved closer to the pinhole screen, the image will be proportionately smaller, whereas if it is moved farther away, the image will be proportionately larger. Excellent sharp photographs of stationary objects can be made with this arrangement. By making a pinhole in one end of a small box and placing a photographic film or plate at the other end, taking

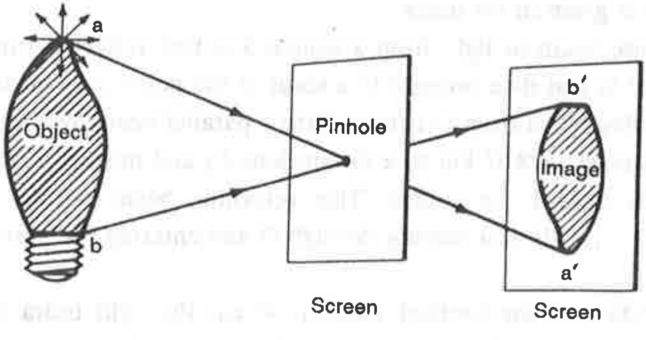


Figure 4-1. A Demonstration Experiment Illustrating the Principle That Light Rays Travel in Straight Lines. The rectilinear propagation of light.

several time exposures as trial runs, good pictures are attainable. For good, sharp photographs the hole must be very small, because its size determines the amount of blurring in the image. A small square hole is quite satisfactory. A piece of household aluminum foil is folded twice and the corner fold cut off with a razor blade, leaving good clean edges. After several such trials, and examinations with a magnifying glass, a good square hole can be selected.

The Speed of Light

The ancient astronomers believed that light traveled with an infinite speed. Any major event that occurred among the distant stars was believed to be observable instantly at all other points in the universe.

It is said that around 1600 Galileo tried to measure the speed of light but was not successful. He stationed himself on a hilltop with a lamp and his assistant on a distant hilltop with another lamp. The plan was for Galileo to uncover his lamp at an agreed signal, thereby sending a flash of light toward his assistant. Upon seeing the light the assistant was to uncover his lamp, sending a flash of light back to Galileo, who observed the total elapsed time. Many repetitions of this experiment, performed at greater and greater distances between the two observers, convinced Galileo that light must travel at an infinite speed.

We now know that the speed of light is *finite* and that it has an approximate value of

$$v = 300{,}000 \text{ km/s} = 186{,}400 \text{ mi/s}$$

In 1849 the French physicist Fizeau became the first man to measure the speed of light here on earth. His apparatus is believed to have looked like Figure 4-2. His account of this experiment is quite detailed, but no diagram of his apparatus is given in his notes.

An intense beam of light from a source S is first reflected from a half-silvered mirror G and then brought to a focus at the point O by means of lens L_1. The diverging beam from O is made into a parallel beam by lens L_2. After traveling a distance of 8.67 km to a distant lens L_3 and mirror M, the light is reflected back toward the source. This returning beam retraces its path through L_2, O, L_1, half of it passing through G and entering the observer's eye at E.

The function of the toothed wheel is to cut the light beam into short pulses and to measure the time required for these pulses to travel to the distant mirror and back. When the wheel is at rest, light is permitted to pass

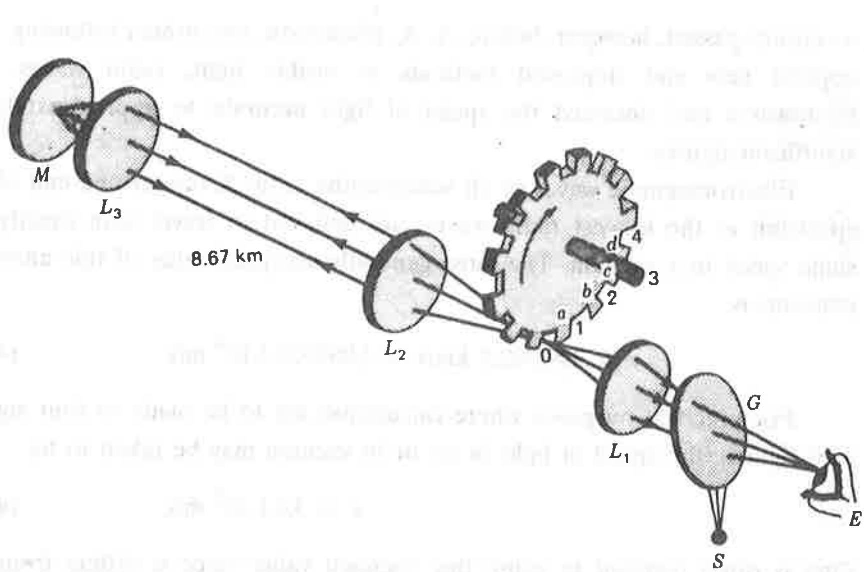


Figure 4-2. Experimental Arrangement Described by the French Physicist Fizeau, With Which He Determined the Speed of Light in Air in 1849.

through one of the openings at *O*. In this position all lenses and the distant mirror are aligned so that an image of the light source *S* can be seen by the observer at *E*.

The wheel is then set rotating with slowly increasing speed. At some point the light passing through *O* will return just in time to be stopped by tooth *a*. At this same speed light passing through opening 1 will return in time to be stopped by the next tooth *b*. Under these circumstances the light *S* is completely eclipsed from the observer. At twice this speed the light will reappear and reach a maximum intensity. This condition occurs when the light pulses getting through openings 1, 2, 3, 4, ... return just in time to get through openings 2, 3, 4, 5, ... , respectively.

Since the wheel contained 720 teeth, Fizeau found the maximum intensity to occur when its speed was 25 rev/s. The time required for each light pulse to travel over and back could be calculated by $(\frac{1}{720})(\frac{1}{25}) = 1/18{,}000$ s. From the measured distance over and back of 17.34 km, this gave a speed of

$$v = \frac{d}{t} = \frac{17.34\ \text{km}}{1/18{,}000\ \text{s}} = 312{,}000\ \text{km/s}$$

In the years that followed Fizeau's first experiments on the speed of light, a number of experiments improved on his apparatus and obtained more and more accurate values for this universal constant. About three-quarters of a century passed, however, before A. A. Michelson, and others following him, applied new and improved methods to visible light, radio waves, and microwaves and obtained the speed of light accurate to approximately six significant figures.

Electromagnetic waves of all wavelengths, from X rays at one end of the spectrum to the longest radio waves, are believed to travel with exactly the same speed in a vacuum. The most generally accepted value of this universal constant is

$$c = 299{,}792.5 \text{ km/s} = 2.997925+10^{8} \text{ m/s} \qquad (4\text{-}1a)$$

For practical purposes where calculation are to be made to four significant figures, the speed of light in air or in vacuum may be taken to be

$$c = 3.0+10^{8} \text{ m/s} \qquad (4\text{-}1b)$$

One is often justified in using this rounded value since it differs from the more accurate value in Eq. (4-1a) by less than 0.1 percent.

Jenkins, F. A., & White, H. E. (1976: pp. 4-8).

Part I. Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The research done by Michelson and others following him was not limited to the visible light.

.... 2. Electromagnetic waves with different wavelengths travel with different speed in a vacuum.

.... 3. The speed of light is calculated with the same accuracy regardless of the purpose.

.... 4. Man has recently become interested in the study of light.

.... 5. Regardless of the distance between the source of a light and a screen, the light will travel in straight lines.

.... 6. The reason that Galileo did not succeed in measuring the speed of light is that he could not think of more efficient and ingenious ways of measuring it.

.... 7. The observer in Fizeau's experiment was able to observe all of the returning beams of light.

.... 8. Michelson and others following him were able to get more accurate results from their attempts in measuring the speed of light.

B. Choose a, b, c, or d which best completes each item.

1. In the pinhole camera, the image formed on a photographic film will be ....
   a. small
   b. straight
   c. large
   d. inverted
2. According to the principle of rectilinear propagation of light, if the hole of a pinhole camera is ....
   a. small, the image produced will be blurred
   b. large, the image produced will be blurred
   c. small, the image produced will be sharp
   d. large, the image produced will be sharp
3. There is .... relationship between the distance of the image screen and the pinhole screen.
   a. a direct
   b. an indirect
   c. a proportionate
   d. a disproportionate
4. The fact that light travels with a finite speed was ....
   a. first discovered by Michelson in the 20th centur
   b. known to man from the earliest times
   c. first discovered by Fizeau in the 19th century
   d. known to Galileo in the 17th century
5. The value of the speed of light is suitable for practical purposes is ....
   a. $2.997925+10^8$ m/s
   b. 300,000 km/s
   c. $3.0+10^8$ m/s
   d. 312,000 km/s
6. In Fizeau's experiment before increasing the speed of the wheel, the light traveling from the source G was reflected and ....
   a. passed through the same opening
   b. stopped by the next tooth
   c. passed through the next opening
   d. stopped by the same tooth
7. It is understood from the passage that ....
   a. once a beam of light originates from a source, it is observable instantly at all other places
   b. a beam of light travels at an infinite speed which cannot be calculated
   c. a beam of light originating from a source cannot be seen instantly if it is far away
   d. it will take some time to observe a beam of light originating from a source

C. Answer the following questions orally.

1. How many lenses did Fizeau use in his experiment?
2. What was the role of the toothed wheel in Fizeau's experiment?
3. At what stage of Fizeau's experiment will the observer not be able to see the light S?
4. What is the use of the pinhole camera?
5. How accurate were the measurements of Michelson and others following him?
6. Why did Galileo not succeed in measuring the speed of light?
7. Why did Michelson and other scholars following him continue Fizeau's work?

Part II. Language Practice

A. Choose a, b, c, or d which best completes each item.

1. Any device which causes a beam of rays to converge or .... on passing through it is called lens.

a. depart	c. digress
b. deviate	d. diverge

2. The study of the agency by means of which a viewed object .... the observer's eye is called optics.

a. touches	c. impresses
b. influences	d. strikes

3. A lens which causes a parallel beam of light passing .... it to spread out is called a diverging lens.

a. through	c. below
b. above	d. under

4. The fact that light travels in straight lines, as is .... from the formation of shadows and other everyday experience is referred to as the rectilinear propagation of light.

a. distinct	c. evident
b. plain	d. manifest

5. Electromagnetic radiation within wavelengths ranging from very short radio waves to the infrared .... are called microwaves.

a. circle	c. vicinity
b. region	d. circuit

6. The nature of electromagnetic radiations which are emitted by matter .... their frequency.

a. rests on	c. depends upon
b. trusts	d. lies on

B. Fill in the blanks with the appropriate form of the words given.

1. Approximately

a. When we see 2.0, we know that something has been measured, and that the result of the measurement is .... two units.

b. Five inches is the .... length of this line.

2. Exactly

a. What is the .... amount of the bill?

b. The line is not .... five inches.

3. Entirely

a. Over some cities, the .... atmosphere is poisoned.

b. Conditions are not .... favorable for the establishment of a private school in this district.

4. Simultaneously

a. The moment when light leaves a distant star and the moment when it reaches our eyes are not ....

b. The telephone bell and the front door bell rang ....

5. Comparatively

a. The .... efficiency of the female workers was very noticeable.

b. The amount of oil they were able to extract from the second well was .... small.

c. A .... of the geometric and wave optics would reveal significant differences.

d. Interference and diffraction cannot be ...., despite the fact that both are dealt with in wave optics.

6. Ultimately

a. The .... products of this kind of education are people who think alike, dress alike, and have no ideas of their own.

b. .... we will be obliged to rely on atomic power as our main source of energy.

C. Fill in the blanks with the following words.

perpendicular	refracted	plane
reflection	incident	law
directions	angle	ray

Whenever a ray of light is .... on the boundary separating two different media, part of the .... is reflected back into the first medium and the remainder is .... (bent in its path) as it enters the second medium. The .... taken by these rays can best be described by two well-established laws of nature.

According to the simplest of these laws, the angle at which the incident ray strikes the interface *MM'* is exactly equal to the .... the reflected ray makes with the same interface. Instead of measuring the angle of incidence and the angle of .... from the interface *MM'*, it is customary to measure both from a common line .... to this surface. This line *NN'* in the diagram is called the *normal.* As the angle of incidence ϕ increases, the angle of reflection also increases by exactly the same amount, so that for all angles of incidence

$$\text{angle of incidence} = \text{angle of reflection}$$

A second and equally important part of this .... stipulates that the reflected ray lies in the .... of incidence and on the opposite side of the normal, the plane of incidence being defined as the plane containing the incident ray and the normal.

D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. They exhibit strong absorption at shorter wavelength, usually 200 nm and below.

b. This phenomenon is known as dispersion

c. The refractive index of a given material is not independent of wavelength, but generally increases slightly with decreasing wavelength.

d. (Near the absorption edge at 200 nm, the index of glass increases sharply.)

e. Most common optical materials are transparent in the visible region of the spectrum, whose wavelength ranges from 400 to 700 nm.

f. Dispersion can be used to display a spectrum with a prism; it also gives rise to unwanted variations of lens properties with wavelength.

1	2	3	4	5	6

Wave Optics

In this section we discuss certain optical phenomena for which geometric or ray optics is insufficient. Primarily *interference* and *diffraction*, these phenomena arise because of the *wave nature of light* and often cause sharp departures from the rectilinear propagation assumed by geometric optics. For one thing, diffraction is responsible for limiting the theoretical resolution limit of a lens to a finite value. This is incomprehensible on the basis of ray optics.

Diffraction

Although the distinction is sometimes blurry, we shall say that *diffraction* occurs when light interacts with a single aperture. Interference occurs when several beams interact. If a screen has several apertures, we can say that each aperture causes a spreading of the beams by diffraction. Far from the screen the beams overlap. This results in an *interference pattern.*

Diffraction is observed *whenever* a beam of light is restricted by an opening or by a sharp edge. Diffraction is very often important even when the opening is many orders of magnitude larger than the wavelength of light. However, diffraction is most noticeable when the opening is only somewhat larger than the wavelength.

We can account for diffraction, or at least rationalize its existence, by *Huygens's construction.* Today, we interpret Huygens's construction as a statement that each point (or infinitesimal area) on a propagating wavefront itself radiates a small spherical wavelet. The wavelets propagate a short (really, infinitesimal) distance, and their resultant gives rise to a 'new' wavefront. The new wavefront represents merely the position of the original wavefront after it has propagated a short distance.

More specifically, Huygens's construction is shown in Figure 4-3. The wavefront in this case is a part of a plane wave that has just been allowed to pass through an aperture. A few points are shown radiating spherical wavelets. Both experience and electromagnetic theory indicate that the wavelets are radiated primarily in the direction of propagation. They are thus shown as semicircles rather than full circles.

The spherical wavelets combine to produce a wavefront lying along their common tangent. The new wavefront is nearly plane and nearly identical with the original wavefront. At the edges, however, it develops some curvature owing to the radiation of the end points away from the axis. Succeeding wavefronts take on more and more curvature, as shown, and eventually the wavefront becomes spherical. We then speak of a *diverging wave.*

Double-slit interference occurs because diffraction allows the light from the individual slits to interact. Close to the slits, where diffraction is not always noticeable, interference is not observed. Only the geometrical shadow of the slits is seen. Far enough from the slits, when the divergence due to diffraction is appreciable, the diffracted beams begin to overlap. From this point on interference effects are important.

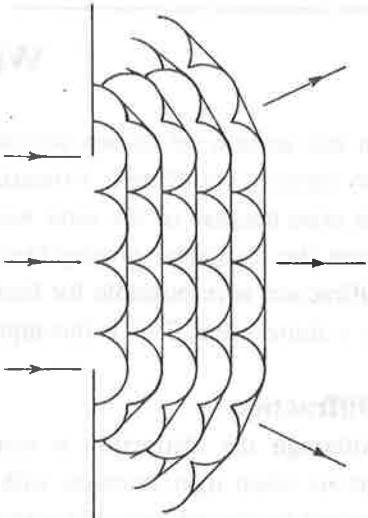


Figure 4-3. Huygen's Construction.

Sufficiently far from the diffracting aperture, we can assume that the rays from the two slits to the point of observation are parallel. This is the simplest case, known as *Fraunhofer diffraction* or *far-field diffraction.*

For most diffracting screens, the observing plane would have to be prohibitively distant to allow observation of Fraunhofer diffraction. The approximation is in fact precise only at an infinite distance from the diffracting screen. Fraunhofer diffraction is nevertheless the important case. This is so because the far-field approximation applies in the focal plane of a lens. One way to see this is to recognize that the diffraction pattern, in effect, lies at infinity. A lens projects an image of that pattern into its focal plane.

The fact can also be seen from Figure 4-4. Rays leaving the diffracting screen at angle θ contribute to the intensity at a single point on the distant observing screen. The lens brings these rays to a point in its focal plane,

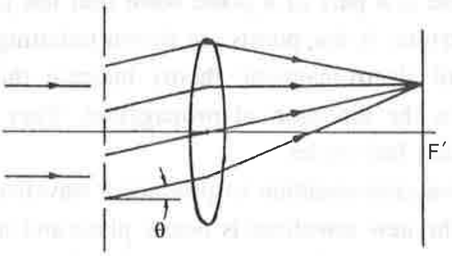


Figure 4-4. Fraunhofer Diffraction in the Focal Plane of a Lens.

where they contribute to the intensity of that point.

In paraxial approximation, all paths from the lens to the point are equal, so no unwanted path lengths are introduced by the lens. The same is true of a well corrected lens, and a true Fraunhofer pattern is observed only with well corrected optics.

Finally, we have been tacitly assuming that the diffracting screen is illuminated with plane waves. If this is not so and it is illuminated with spherical waves originating from a nearby point source, the pattern at infinity is not a Fraunhofer pattern. It is nevertheless possible to observe Fraunhofer diffraction with a well corrected lens; it can be shown that the Fraunhofer pattern lies in the plane into which the lens projects the image of the point source, no matter what the location of the source. Illuminating with collimated light is just a special case.

Young, M. (1986: pp. 69, 82-84).

Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The interaction of the light from individual apertures can be accounted for by interference.

.... 2. The interference effects are significant at the points where beams of light overlap.

.... 3. Presumably, the rays from the two apertures are parallel at the far-field diffraction.

.... 4. The diffracting rays brought about to a focal point contribute to the intensity of that single point.

.... 5. If the diffracting screen is illuminated with spherical waves, the pattern produced will be Fraunhofer pattern.

.... 6. With a well-corrected lens the location of the source of light is insignificant in forming the Fraunhofer pattern.

.... 7. The distinction between interference and diffraction is quite obvious.

B. Choose a, b, c, or d which best completes each item.

1. One of the reasons for the limitation of geometric optics in explaining certain optical phenomena is that it ....
   a. is restricted to the study of light beams in straight lines
   b. ignores the fact that wavefronts can be divided into two or more segments and recombined elsewhere

c. studies only those waves in the world around us that can be detected by our senses

d. does not make use of electromagnetic devices

2. The geometric optics assumes that ....

a. light travels in straight lines

b. a lens has infinite values

c. several beams of light can interact

d. divided light beams can be recombined

3. The difference between interference and diffraction is that in the first case ....

a. there is a single aperture at work, but in the latter there are several

b. there are several apertures at work, but in the latter there is a single one

c. there is a single beam of light at work, but in the latter there are several beams of light

d. the beams interact far from the screen, but in the latter they interact very close to the screen

4. Diffraction is most remarkable when ....

a. a beam of light is restricted by an aperture

b. the aperture is considerably larger than the wavelength of light

c. a beam of light is restricted by a sharp edge

d. the aperture is slightly larger than the wavelength of light

5. According to Huygens's rule, ...

a. semicircle wavefronts change to straight waves when they approach a barrier

b. when waves pass through an aperture, they always spread to some extent

c. each point on a wavefront may be regarded as a new source of waves

d. diffraction of light can be illustrated successfully with water waves

6. The phenomenon of 'diverging wave' refers to the fact that ....

a. the new waves produced represent the original curvature of the wavefront

b. the combination of small waves finally leads to a new wavefront

c. wavelets produced at the axis have more curvature than the ones at the end points

d. as waves propagate, they will turn aside from a straight course

C. Write the answers to the following questions.

1. Which of the optical phenomena cannot be explained by the geometric optics?
2. What does interference pattern of wavefront mean?
3. What will happen if the diffracting screen is illuminated with spherical waves?
4. What does the diffraction of a beam of light mean?
5. What is the role of a corrected lens in observing Fraunhofer diffraction?
6. What does diverging wave mean?
7. What is Huygens's principle?
8. What does double-slit interference mean?
9. Why do the observing planes of diffracting screens have to be far away?

Section Three: Translation Activities

A. Translate the following passage into Persian.

Coherence

Until now, we have almost always assumed light to be completely *coherent,* in the sense that any interference experiment resulted in high-quality interference fringes. In general, this is not the case, except with certain laser sources; the light from most sources is said to be *incoherent* or *partially coherent*.

When conditions are such that the light is incoherent, it is not possible to detect interference effects. A discussion of wave optics is incomplete without considering the conditions that must exist for an interference experiment to be performed successfully.

Light sources are today put into one of two categories, laser sources and *thermal sources.* A typical thermal source is a gas-discharge lamp. In such a lamp, light is emitted by excited atoms that are, in general, unrelated to each other. Each atom emits relatively short bursts or *wave packets.* If an atom is excited several times, it can emit several consecutive wave packets. These packets are generally far apart (compared with their duration) and are emitted randomly in time. The packets emitted by a single atom therefore bear no constant phase relation with each other.

Suppose we try to perform interference by division of amplitude with the packets emitted by a single atom. The wave reflected from the second surface is delayed with respect to the first because of the finite speed of light. If the delay is greater than the duration of the wave packet, the two reflected packets will not reach the detector simultaneously. There will therefore be no interference pattern, and we would compute the intensity at the viewing screen by adding the intensities (not amplitudes) of the reflected waves. The light is said to be incoherent for the purpose of this experiment.

B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. absorption edge ....
2. accurate value ....
3. aperture ....
4. collimated light ....
5. common tangent ....
6. diffracting screen ....
7. diffraction ....
8. dispersion ....
9. diverging beam ....
10. double-slit interference ....
11. far-field diffraction ....
12. geometric optics ....
13. Huygens's construction ....
14. image screen ....
15. incident ....
16. index of refraction ....
17. infinitesimal area ....
18. interface ....
19. interference ....
20. light beam ....
21. light pulse ....
22. maximum intensity ....
23. paraxial approximation ....
24. perpendicular ....
25. pinhole camera ....
26. plane of incidence ....
27. prism ....

28. propagation wavefront ....
29. ray optics ....
30. rectilinear propagation ....
31. reflection ....
32. refraction ....
33. refractive index ....
34. spectrum ....
35. spherical wavelength ....
36. transparent ....
37. universal constant ....
38. wavelength ....

Unit 5

Section One: Reading Comprehension

Lasers

There is one type of light source in which the atoms emit waves that are in phase. It is called a *laser.* Many types of lasers are available, but they all operate on the principle from which they get their name, *light amplification* by *stimulated emission of radiation*. The concept of stimulated emission was first presented clearly by Einstein in 1917. It was not until 1953, however, that the concept was applied to laserlike devices. In that year a microwave laser, called a *maser,* was developed. Lasers, which use light rather than microwaves, were first conceived and constructed in 1958.

To begin our discussion, refer to Figure 5-1, which illustrates the absorption of a photon by an atom. The photon must have the same energy as the difference in energy between the two atomic levels shown. Let us call this energy E_2-E_1.

Now let us suppose that photons of energy E_2-E_1 are incident on an atom that is already excited, as shown in Figure 5-2. The energy of the incident photon exactly equals the energy that the atom must eject if it falls to its lower energy state. Einstein showed that such incident photons *stimulate* the excited atom to fall to the lower state. Moreover, as shown in the Figure, *the photon ejected by the atom as it falls to the lower state is in phase with the incident photon that stimulated it to make the transition.* This process is fundamental to the operation of the laser.

There is a subtle point involved here, however, that will become important for us later. Absorption and stimulated emission are competing

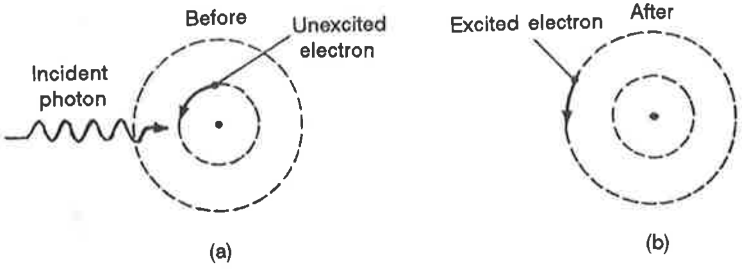


Figure 5-1. Absorption of a Photon.

processes. If the proportion of excited atoms is too small, then most of the photons incident on the atoms will be absorbed. Only if there are more excited than unexcited atoms will the incident beam increase in intensity as it passes by the atoms. Only then will stimulated emission exceed absorption. We therefore require a *population inversion* (more excited than unexcited atoms) if stimulated emission is to prevail.

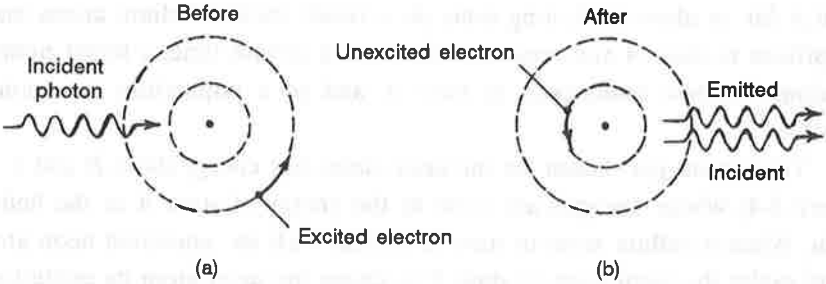


Figure 5-2. Stimulated Emission Produces Waves That Are in Phase.

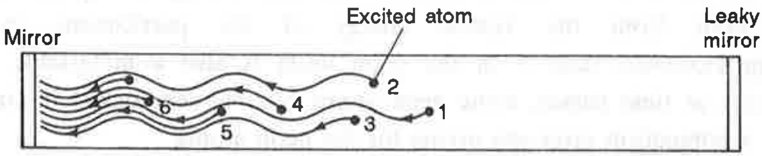


Figure 5-3. Schematic Diagram Showing How Stimulated Emission Builds up a Strong Coherent Set of Waves in a Laser Tube.

The type of laser described here is the helium-neon laser you will probably encounter in your laboratory work. Its basic element is a glass tube filled with a low-pressure mixture of helium and neon in the ratio of about 15% helium to 85% neon. The ends of the tube are sealed with mirrors, as shown in Figure 5-3.

One of these mirrors is only lightly silvered, so it allows a small amount of light to leak out from the end of the tube. The gas atoms in the tube are excited by a gas discharge produced within the tube by various means.

The gas discharge causes many of the helium and neon atoms to be excited. As they fall back to their lower energy states, they give off the light we normally associate with neon signs. The atoms are emitting their waves in an uncoordinated way, and so the light waves are incoherent. To obtain predominantly coherent waves, we must have a population inversion so that stimulated emission will predominate. The gases helium and neon are used in the laser tube because they are capable of achieving a population inversion in the following simple way.

Because of the gas discharge in the laser tube, many helium (and neon) atoms are excited to various energy states. As shown in the energy-level diagrams of Figure 5-4 helium has an energy state A that is 20.6 eV higher than the ground state of the atom. This state is what is called a *metastable state.* In such a state, the atom resists falling to lower states, and so it exists in state *A* for an abnormally long time. As a result, excited helium atoms make transitions to state *A* and remain there. Over a certain time, a larger number of atoms become semilocked in state *A*, and so a population inversion is possible.

The second gas chosen for the laser, neon, has energy states *B* and *C* (in Figure 5-4) whose energies are close to the energy of state *A* in the helium atom. When a helium atom in state *A* collides with an unexcited neon atom, it can excite the neon atom to state *B* by giving the neon atom its excitational energy. (Actually, the excited neon atom in state *B* has slightly more energy than the helium atom in state *A*. This additional energy is acquired by the neon atom from the kinetic energy of the participants in the collision.)However, state *B* in the neon atom is also a metastable state. Therefore, as time passes, many neon atoms become semilocked in state *B*, and so a population inversion occurs for the neon atoms.

Let us now return to Figure 5-3, where the tube is now assumed to have enough neon atoms in excited state *B* that a population inversion exists. Eventually one atom (labeled 1) falls to state *C* (Figure 5-4) and emits a photon with energy 1.96 eV (λ=632.8 nm, red). This photon stimulates neon atom 2 to emit a like photon. Then, in succession, a multitude of excited neon atoms emit identical photons that are all in phase, as indicated in Figure 5-3.

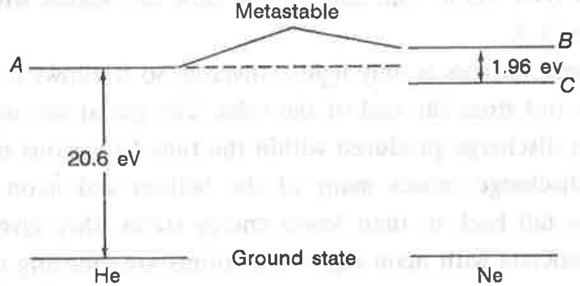


Figure 5-4. Portions of the Energy-Level Diagrams for Helium and Neon. States *A* and *B* are metastable (long-lived)

In a short time the tube is filled with coherent waves moving back and forth between the two mirrors at the ends of the tube. A very intense, monochromatic, coherent beam is set up in the tube. A small fraction of the beam exists from the tube through the leaky mirror at one end.

Because all the waves issuing from the end of the laser tube are in phase, the beam is of high intensity. Its wavelength is sharply defined, 632.8 nm, because all the waves are identical. Not only is the beam intense and coherent, but it also diverges very little. Any rays within the tube that diverged much from the axis of the tube are lost out the sides during the many trips back and forth through the tube. The fact that the beam does not diverge appreciably is of great practical importance. Unlike light from a bulb, the laser beam's energy does not fan out into space. Instead, it flows out into space through a thin cylinder and maintains its intensity over very long distances. For example, the laser shown in Figure 5-5 has a power output of only 0.0005 W. but the light energy is confined to such a narrow cylindrical beam that the laser beam far outshines the high-power conventional bulbs in the foreground.

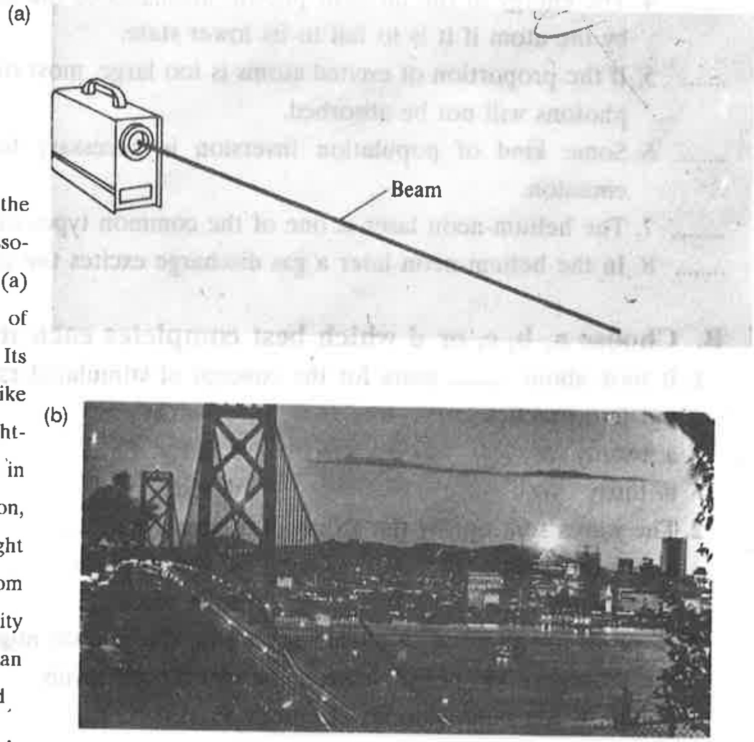


Figure 5-5. Even Though the Electro Optics Associates Laser in (a) Has an Output of Only 0.0005 W, Its Narrow, Needlelike Beam Shines Brightly in the Distance in (b). For comparison, notice the less bright light coming from the high-intensity lamps on the San Francisco-Oakland Bay Bridge.

Lasers find many uses in the modern world. Laser beams capable of extremely high power can be used in high-precision cutting devices for such far-ranging applications as eye surgery and drilling holes in armor plate. Their narrow beams are important in positioning and surveying devices. Lasers are being used increasingly for communication signals in fiber-optic cables replacing conventional telephone lines. These are but a few of the many uses of lasers. It is of note that the laser became possible only as a result of years of basic research during which the seemingly minor details of atomic structure were sorted out.

Bueche, F. J. (1986: pp. 801-803).

Part I. Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. Maser is a kind of laser.

.... 2. Different types of lasers operate on different principles.

.... 3. The two processes of stimulated emission and absorption are compatible.

.... 4. The energy of the incident photon must exceed the energy ejected by the atom if it is to fall to its lower state.

.... 5. If the proportion of excited atoms is too large, most of the incident photons will not be absorbed.

.... 6. Some kind of population inversion is necessary for stimulated emission.

.... 7. The helium-neon laser is one of the common types of laser.

.... 8. In the helium-neon laser a gas discharge excites the gas atoms.

B. Choose a, b, c, or d which best completes each item.

1. It took about .... years for the concept of stimulated emission to be put into practice.
   a. twenty c. forty
   b. thirty d. sixty
2. The waves sent out by the atoms of a laser are ....
   a. out of phase c. out of place
   b. in phase d. in place
3. In order for an atom to absorb a photon, the photon must have .... the difference in energy between the two atomic levels.
   a. almost the same amount of energy as

b. more energy than

c. the same amount of energy as

d. less energy than

4. During a metastable state, excited helium atoms ....

a. remain in state A

b. make transitions to state B

c. make a population inversion impossible

d. fall back to the ground state of the atom

5. In order to obtain coherent waves, ...

a. there is no need for population inversion

b. the light associated with neon signs is needed

c. there should be no leak out from the end of the tube

d. stimulated emission should exceed absorption

6. Absorption will be less than emission if ....

a. the incident beam passes by the atoms

b. there are more excited than unexcited atoms

c. the incident beam equals the ejected energy

d. there are less unexcited than excited atoms

7. The basic process in the operation of the laser is that ....

a. the stimulation of the atom plays the essential role in the transition

b. the incident photons stimulate the atom to make the transition

c. the transition from one energy to a higher one is crucial

d. the ejected photon has to be in phase with incident photon

C. Answer the following questions orally.

1. Which scholar suggested the concept of the stimulated emission for the first time?
2. What makes it possible for a small amount of light to leak out from the helium-neon laser?
3. What excites the gas atoms in the tube?
4. When do the helium and neon atoms give off light?
5. How does a population inversion take place?
6. Why are some of the rays lost out the sides of the tube during the many trips?
7. Why does the laser beam shine much more than an ordinary bulb?

Part II. Language Practice

A. Choose a, b, c, or d which best completes each item.

1. Light consisting of vibrations of .... or nearly the same frequency is called monochromatic light.

   a. the interchangeable — c. the equal

   b. the equivalent — d. the same

2. An excited state of an atom or nucleus which .... an appreciable life-time is called metastable state.

   a. retains — c. has

   b. enjoys — d. holds

3. The addition of energy to a nucleus, an atom, or a molecule .... it from its ground state to a higher energy level is referred to as excitation.

   a. transporting — c. transferring

   b. transplacing — d. transplanting

4. A powerful, ... directional, monochromatic and coherent beam of light is produced by the laser.

   a. eminently — c. prominently

   b. highly — d. sharply

5. A beam of light, or other electromagnetic radiation is said to be coherent if its waves are in ....

   a. phase — c. situation

   b. condition — d. aspect

6. The emission by an atom is an excited quantum state of a photon, as the result of the impact of a photon from outside of .... equal energy is referred to as stimulated radiation.

   a. strictly — c. exactly

   b. definitely — d. correctly

B. Fill in the blanks with the appropriate form of the words given.

1. Inversion

a. When something is ...., it is turned upside down.

b. The resulting mixture is laevorotatory, while a solution of cane-sugar is dextrorotatory, ... of the optical rotation being thus obtained.

c. Examples of .... square law include the illumination of a surface, gravitational field, field due to an electric charge, etc.

d. Inverse square law is a law which states that the intensity of an effect at a point B due to a source at A varies .... as the square of the distance AB.

2. Succession

a. When we say "the school team won four .... games", we mean that the team won four games, one after the other.

b. You cannot describe the temporal ...., because you do not know the order of events which produced the marks.

c. Who .... Einstein as the greatest theoretical physicist?

d. Numbers three, eleven, and seven were flashing .... on the screen.

3. Collision

a. The forces resulting from .... within the system do not change the momentum of the system.

b. When two cars ...., the unbalanced frictional froces on the cars as they slide across the roadway can be neglected if we are concerned only with the short time interval of the actual collision.

4. Amplification

a. If the strength of a current is increased, it is ....

b. The act of increasing the strength of a signal fed into it, by obtaining power from a source other than the input signal is called ....

5. Transition

a. Nuclear .... refers to a change in the configuration of an atomic nucleus.

b. The .... wheather from warm to cold has caused much concern.

c. This irregular arrangement gives all the .... moving elements specially interesting properties.

d. During the adolescence period, children .... from childhood to manhood.

C. Fill in the blanks with the following words.

measurements	oscillation	lasers
phenomena	beyond	field
magnitude	scales	light

An area in both physics and chemistry where the laser has dramatically improved previously existing possibilities is that of making time-resolved measurements of the behavior of various media after excitation by short light pulses. In fact, while it is possible with conventional .... sources to produce light pulses down to ~1 ns, ... are now able to produce pulses down to ~0.1 ps. This has opened up possibilities for investigating a wide variety of ...., based on the new capability of ultrashort time-resolved measurements.

Since many important processes in physics, chemistry, and biology have time .... in the picosecond range, this is an exciting new development.

Yet another .... where the laser has not only improved previously existing possibilities but also introduced quite new concepts is that of spectroscopy. It is now possible with some lasers to narrow the .... bandwidth down to a few tens of kilohertz (both in the visible and infrared), and this allows spectroscopic .... to be made with a resolving power many orders of .... (from 3 to 6) higher than that obtainable by conventional spectroscopy. The laser has also spawned the new field of nonlinear spectroscopy which allows spectroscopic resolution to be extended well .... the limit normally imposed by Doppler broadening effects. This has led to new and more detailed studies of the structure of matter.

D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. The position of the laser beam on the receiver is determined by the value of photocurrent from each quadrant.

b. In this field the laser has very largely replaced the optical instruments used previously, such as collimators or telescopes.

c. Alignment is then dependent on simple electrical measurements, thus avoiding the reliance on subjective judgement by the operate.

d. The laser's directionality makes it ideal for establishing a straight reference line for aligning machinery for aircraft construction, and for civil engineering uses such as constructing buildings, bridges, or tunnels.

e. One of the most common industrial applications of lasers is for alignment purposes.

f. One generally uses a visible He-Ne laser of low power, and alignment is often achieved with the help of solid-state detectors in the form of quadrants.

g. The alignment precision obtainable in practice in a workshop ranges from ~5 μm to ~25 μm.

1	2	3	4	5	6	7

Laser Safety

Probably the most dangerous aspect of many lasers is the power supply. Still, the beam emitted by some lasers can be harmful to the eyes or even the skin. Therefore, it is worthwhile to dwell on the dangers posed by lasers and other intense sources.

Radiation can harm the eye in several ways, depending on the wavelength. Ultraviolet light below 300 nm or so can 'sunburn' the cornea or, at higher intensity, the skin. Slightly longer-wavelength uv radiation penetrates the cornea at least in part and is obsorbed in the lens. It may cause a *cataract,* or opacity of the lens. Visible and near-ir radiation through about 1.4-μm wavelength penetrates fairly efficiently to the retina, where it may be focused to a small spot and cause either photochemical or thermal damage. Radiation between the wavelengths of 1.4 and 3 μm penetrates to the lens and may cause cataracts; longer-wavelength infrared radiation is absorbed near the surface of the cornea and can cause damage there. Even microwave radiation, because of its ability to heat tissue, has been implicated in the formation of cataracts.

Laser sources have been placed into four classes defined by the lasers' ability to cause damage to the eye. These are usually designated by Roman numerals from I to IV. Class I lasers are believed to be unable to cause damage even when shone directly into the eye for an extended period of time. Class II lasers emit low-power visible radiation that can probably not cause damage within 0.25 s if shone directly into the eye: the duration, 0.25 s, is assumed to be the time required for an aversion response, in this case, a blink. In the visible and near-ir regions, Class II lasers are those that emit between approximately 1 μW (depending on wavelength) and 1 mW. There are fairly large safety factors built into the classification, but a glance down a Class II laser should not be encouraged.

Class III lasers are those that can create a hazard in less than 0.25 s. Class IV lasers are those that can create dangerous levels of radiation by diffuse reflection. Many Class IV lasers are also fire hazards or emit so much power that they can vaporize whatever is used to block the beam and thereby put dangerous chemicals (such as beryllium compounds) into the air. All lasers except Class I lasers must have labels that state the laser's classification. In addition, operators of Class II and IV lasers are required to employ a variety of safety measures to protect themselves as well as more casual passers-by.

To put the laser-classification scheme into perspective, let us compare the retinal irradiance levels that result from a direct look at the sun and a direct look down a 1-mW He-Ne laser. The sun subtends about 10 mrad and delivers an irradiance about equal to 100 mW cm^{-2} at the earth's surface. The focal length of the eye is about 25 mm, so the image of the sun has a diameter of about 25 mm times 10 mrad, or 0.25 mm. If the eye is bright adapted, the pupil diameter is approximately 2 mm, and the total power incident on the pupil is about 3 mW. The irradiance is equal to this power divided by the area of the image, or 6 W cm^{-2}. Had the eye been dark adapted immediately before the exposure, the pupil diameter might have been as much as 8 mm. Then the retinal irradiance could have been as much as 100 mW cm^{-2}.

Now let us assume that a 1-mW laser with a 2-mm beam diameter (1-mm beam width w) is aimed directly into the eye. With a 2-mm pupil, the eye is diffraction limited, so we assume diffraction-limited imagery in this case. If the wavelength of the laser is 633 nm, the radius of the beam waist on the retina is $\lambda f'/\pi w$, or about 5 μm. The average irradiance inside a circle with this radius is about 1 kW cm^{-2}, or about 200 times more than the irradiance brought about by the sun; the total focused powers are roughly equal. Whether power or irradiance is the important quantity depends on the mechanism of damage. In any case, looking down the bore of a common, 1-mW He-Ne laser is at least roughly comparable to looking directly at the sun. Those who suffer from eclipse blindness can attest that the full power of the sun is not necessary to bring about permanent damage in a relatively short time.

Sunglasses. Long-term exposure to relatively high irradiance levels can cause damage to the retina, whether or not the light is coherent. The blue and ultraviolet spectral regions can cause photochemical damage at irradiances far below the threshold for visible burns. Light of these wavelengths may be implicated in *senile macular degeneration*, a disorder that causes elderly people to lose their visual acuity.

The danger from the short-wavelength radiation is potentially increased with some sunglasses if they are on average dark enough to increase the pupil diameter and yet are manufactured so that they transmit harmful wavelengths selectively. Therefore, sunglasses should probably be designed for greater attenuation of wavelengths below about 550 nm; they should at any rate not exhibit high transmittance at wavelengths just shorter than visible light. Unfortunately, some sunglasses, among them some polarizing sunglasses, exhibit high transmittance at wavelengths just shorter than visible light.

Unfortunately, some sunglasses, among them some polarizing sunglasses, exhibit high transmittance at wavelengths just shorter than visible light. Unfortunately, some sunglasses, among them some polarizing sunglasses, exhibit high transmittance just below 400 nm. A rule of thumb, which is not necessarily accurate, states that yellow or brown lenses are less likely to transmit short-wavelength radiation than are neutral or gray lenses. [Glasses that have colored lenses (especially blue lenses) and are not specifically described as 'sunglasses' should probably be avoided entirely.]

There is also speculation that ambient levels of infrared radiation may be harmful to the eye, but this is less well established. Many sunglasses tend to transmit near-infrared radiation rather efficiently, and this also might cause a hazard if the pupil dilates significantly. Another rule of thumb, again not necessarily applicable to all cases, suggests that metal-coated sunglasses are the least likely to have high-transmittance windows at wavelengths other than those of visible light.

Young, M. (1986: pp. 171-172).

Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. All four classes of laser are harmful to the eye.

.... 2. The most dangerous aspect of lasers is their intense source of power.

.... 3. Microwave radiation is incapable of damaging the eye.

.... 4. Duration of the time lasers shone into the eye is a factor of their damage for the eye.

.... 5. The requirement of taking safety measures against the laser radiation does not include casual passers-by.

.... 6. High transmittance just below 400 nm can be harmful to the eye.

.... 7. The incoherent light waves are not dangerous to the retina.

.... 8. There is a direct relationship between the class of the laser source and the amount of its danger to the eye.

.... 9. Long-term exposure to high irradiance levels can cause senile macular degeneration regardless of the age of the people involved.

B. Choose a, b, c, or d which best completes each item.

1. Opacity of the lens might be caused by ....
   a. ultraviolet light below 300 nm

b. ultraviolet light with longer-wavelenghts than 300 nm
c. near-irradiation through about 1.4 μm wavelength
d. microwave radiation

2. Class II lasers might not damage the eye if they ....
   a. do not put dangerous chemicals into the air
   b. shone directly into the eye for a split second
   c. do not shone directly into the eye within 0.25 s
   d. have labels stating their classification
3. The comparison of the retinal irradiance levels brought about by a direct look at the sun and a direct look down a 1-mW He-Ne laser reveals that ....
   a. the average irradiance of the sun is 200 times more than that of the laser
   b. the sun is more dangerous than the laser
   c. the laser is more dangerous than the sun
   d. the average irradiance of the laser is about 100 mW cm^{-2}
4. Photochemical damage to the eye can take place ....
   a. if sunglasses are not used carefully
   b. at irradiances for above the invisible burns
   c. if polarizing sunglasses are used
   d. at irradiances much below the threshold for visible burns
5. It is suggested in the passage that ....
   a. all of the sunglasses will prevent the damage of high radiation to the eye
   b. glasses with blue lenses are the best kind of sunglasses
   c. very dark sunglasses are not dangerous to the eye
   d. generally speaking sunglasses with yellow lenses are the safest

C. Write the answers to the following questions.

1. Which class of lasers are not harmful to the eye?
2. Why are class IV lasers the most dangerous to the eye?
3. Why is the average irradiance of a 1-mW He-Ne laser more dangerous than that of the sun?
4. Why will some sunglasses increase the danger of short-wavelength radiation?
5. What is the advantage of metal-coated sunglasses?
6. What is the criterion for the classification of laser sources into four classes?

7. What kind of radiation may cause a cataract?
8. How can sunglasses protect the eye from the high radiation?

Section Three: Translation Activities

A. Translate the following Passage into Persian.

Applications of Lasers

Applications in Physics and Chemistry

The invention of the laser and its subsequent development have depended on fundamental knowledge drawn from the fields of physics and (to a lesser extent) chemistry. It was therefore natural that applications of the laser to physics and chemistry should have been among the first to be considered.

In physics the laser has initiated quite new fields of investigation and has dramatically stimulated some already existing fields. It should also be **recognized that the study of laser behavior and the interaction** of laser beams with matter themselves constitute new areas of study within the field of physics. A particularly **interesting example of a new area** of investigation is that of nonlinear optics. The high intensity of a laser beam makes it possible to observe new phenomena arising from the nonlinear response of matter. We mention in particular the following processes: (i) harmonic generation whereby suitable materials, when excited by a laser beam at frequency ν, can produce a new coherent beam at frequency $2\,\nu$ (second harmonic), $3\,\nu$ (third harmonic), etc.; (ii) stimulated scattering. In this case the incident laser beam at frequency ν interacts with a material excitation at frequency ν_q (e.g., an acoustic wave) to produce a coherent beam at frequency ν-ν_q (Stokes scattering). The energy difference between the incident photon, $h\nu$, and the scattered photon, $h(\nu-\nu_q)$, is given to the material excitation. Particularly important examples of stimulated scattering phenomena are stimulated Raman scattering (which, in its most frequently encountered form it involves a material excitation consisting of an internal vibration of each molecule of the material) and stimulated Brillouin scattering (wherein the material excitation consists of an acoustic wave). Both of these processes can occur with high conversion efficiency (often several tens of percent). For this reason both harmonic generation and stimulated scattering (in particular Raman scattering since it can involve a large frequency shift) are used in practice to generate intense coherent beams at new frequencies.

B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. ambient level ....
2. amplification ....
3. armor plate ....
4. beam diameter ....
5. coherent waves ....
6. cylindrical beam ....
7. dextrorotatory ....
8. diffuse reflection ....
9. excitational energy ....
10. fiber-optic cables ....
11. gas discharge ....
12. gravitational field ....
13. ground state ....
14. high photon ....
15. high transmittance ....
16. incident photon ....
17. incoherent light ....
18. infrared radiation ....
19. in phase ....
20. intense source ....
21. inverse square law ....
22. irradiation ....
23. laevorotatory ....
24. metastable state ....
25. monochromatic ....
26. optical rotation ....
27. population inversion ....
28. retinal irradiance ....
29. senile macular degeneration ....
30. short-wavelength ....
31. stimulated ....
32. ultraviolet light ....
33. unexcited electron ....
34. visual acuity ....

Unit 6

Section One: Reading Comprehension

Modern Physics

Black-Body Radiation

The first indication of the inadequacy of classical physics emerged around 1900 from the study of thermal radiation, or 'radiant heat' emitted by hot bodies. This is electromagnetic radiation containing a wide variety of wavelengths. The intensity and the predominant wavelength of the radiation varies with the temperature of the body. For instance, at a temperature of 5800 K (the surface temperature of the Sun), much of the thermal radiation takes the form of visible light–the body therefore looks bright white. At a temperature of 1200 K, the intensity is lower and most of the thermal radiation lies in the near infrared, with only a small amount of visible light–the body exhibits a deep red glow. At room temperature, the intensity is very low and most of the radiation lies in the far infrared–the body gives off no light visible to the human eye.

The spectrum of thermal radiation is continuous, i.e., the energy of the radiation is smoothly distributed over all wavelengths or, equivalently, over all frequencies. For instance, Figure 6-1 shows the spectrum of thermal radiation emitted by the Sun as a function of frequency. The quantity S_ν plotted in this Figure is called the **spectral emittance**. This is the energy flux (or power per unit area) emitted by the glowing surface per unit frequency interval; thus $S_\nu d\nu$ is the energy flux emitted in a small frequency interval from ν to $\nu+d\nu$. Note that the spectral emittance is small at very high and at very low frequencies, and that it has a broad peak with a maximum near the visible region, at $\nu=3.4\times10^{14}$ Hz.

The thermal radiation emerging from the surface of a glowing body is generated within the volume of the body by the random thermal motions of atoms and electrons. Before the radiation reaches the surface and escapes, it is absorbed and reemitted many times, and it attains thermal equilibrium with the atoms and electrons. This equilibration process shapes the continuous spectrum of the radiation, completely washing out all of the original spectral features of the radiation. Hence the spectrum of the radiation within the volume of the body depends only on the temperature, not on the kind of

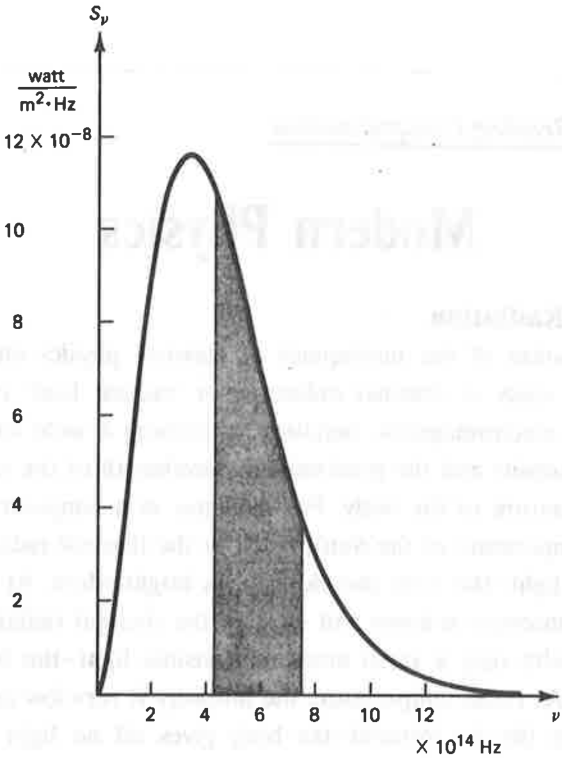


Figure 6-1. Spectral Emittance of the Sun (5800 K). In this plot the discrete dark spectral lines (Fraunhofer lines), which result from the blocking out of some of the thermal radiation by gas in the solar atmosphere, have been ignored. The shaded band indicates the visible region.

atoms in the body.

The flux of thermal radiation emerging from the surface of a glowing body depends to some extent on the characteristics of the surface. The surface usually permits the escape of only a fraction of the flux reaching it from inside the body. Likewise, if the body is immersed in a bath of thermal radiation of the same temperature as the body, then the surface permits the ingress of only an equal fraction of the flux reaching it from outside, reflecting the rest. This equality of the emissive and absorptive characteristics of the surface can readily be established by appealing to the Second Law of Thermodynamics, according to which heat cannot flow sponstaneously from a colder system to a hotter system. If the body were to emit more radiation than it absorbs from the bath of radiation, then its temperature would decrease, and that of the bath of radiation would increase. Heat would therefore be flowing from a colder system to a hotter system, in contradiction to the Second Law.

The equality of the emissive and absorptive characteristics of the surface of a body implies the following general rule: a good absorber is a good emitter, and a poor absorber is a poor emitter. A body with a perfectly absorbing (and emitting) surface is called a **black body;** such a body would look black under outside illumination. When a black body is hot, its surface emits more thermal radiation than that of any other hot body at the same temperature. In practice the characteristics of an ideal black body are most easily achieved by a trick: take a body with a cavity, such as a hollow cube, and drill a small hole in one side of the cube (see Figure 6-2). The hole then acts like a black body–any radiation incident on the hole from outside will be completely absorbed. Because of this equivalence between a black body and a hole in a cavity, black-body radiation is often called cavity radiation.

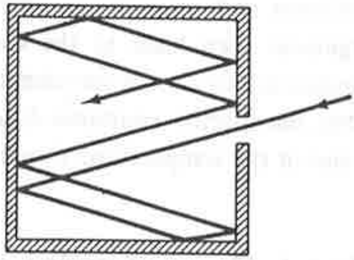


Figure 6-2. A Cavity With a Small Hole. Any radiation entering the hole will remain trapped; it will suffer repeated reflections, and it will ultimately be absorbed by the walls.

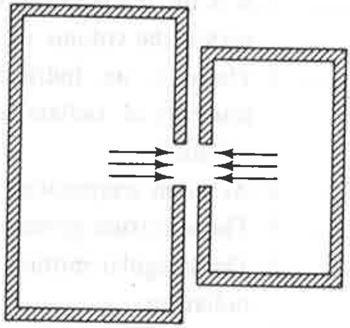


Figure 6-3. Two Cavities With Holes of Equal Size Exchanging Radiation.

The black body plays a preferential role in the study of thermal radiation because its spectral emittance does not depend on the material of which it is made or on any other characteristics of the body–the spectral emittance depends *exclusively on the temperature* of the body. We can prove this by appealing, again, to the Second Law of Thermodynamics. Consider two cavities at equal temperatures with holes of equal size (see Figure 6-3). The cavity on the left radiates into the cavity on the right, and vice versa. If the flux emitted by the cavity on the left were larger than that of the cavity on the right, the radiative heat transfer would produce an increase of temperature on the right and a decrease on the left, in contradiction to the Second Law. This argument leads us to the conclusion that the fluxes emitted by both cavities are the same. Furthermore, by a refinement of this argument we can demonstrate that the fluxes in any given small frequency interval $d\nu$ are also the same. We need only make a slight alteration in the arrangement shown in Figure 6-3 by inserting a filter for light between the two cavities, a filter that only permits the passage of radiation of frequencies in an interval from ν to $\nu+d\nu$. Our thermodynamic argument then leads to the conclusion that the fluxes emitted by the two cavities in this chosen wavelength interval must be the same. Thus for a black body, the spectral emittance S_ν must be a universal function of the wavelength λ and of the temperature T, and of nothing else.

Ohanian, H. C. (1987: pp. 107-109).

Part I. Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The 'radiant heat' sent out by hot bodies contains different kinds of wavelengths.

.... 2. It is the temperature that determines the spectrum of the radiation within the volume of the body.

.... 3. There is an indirect relationship between the degree of the intensity of 'radiant heat' and the thermal radiation lying near the infrared.

.... 4. At room temperature, the hot body emits no light.

.... 5. The spectrum given off at the extreme frequencies is too much.

.... 6. The irregular motion of atoms and electrons generates the thermal radiation.

.... 7. It is the kind of atoms that plays an important role in determining the spectrum of the radiation within the volume of the body.

.... 8. The characteristics of the surface have nothing to do with the flux of thermal radiation.

B. Choose a, b, c, or d which best completes each item.

1. The first indication of the inadequacy of classical physics resulted from the study of ....

a. wide variety of wavelengths c. energy quantization
b. electromagnetic radiation d. wave properties of light

2. The higher the intensity of the thermal radiation, ... will be.

a. the higher the related wavelength c. the less visible the light
b. the lower the related wavelength d. the more visible the light

3. The power per unit area given off by the glowing surface per unit frequency interval is known as ....

a. the thermal radiation
b. the radiant heat
c. the spectral emittance
d. the electromagnetic radiation

4. The thermal equilibrium with the atoms and electrons is attained by ....
a. the spectral emittance
b. the thermal radiation
c. the variety of wavelengths
d. the intensity of radiation

5. According to the Second Law of Thermodynamics, ...
a. heat cannot flow from a colder system to a hotter system
b. the emissive and absorptive characteristics of the surface are equal
c. the surface usually allows the escape of only some of the flux
d. heat can flow from a colder system to a hotter system

6. The emission of more radiation by a body than what it absorbs from the bath of radiation will result in .... of its temperature.
a. a flux
b. an equilibrium
c. a decrease
d. an increase

7. The spectrum of radiant heat is equally distributed over all ....
a. frequencies
b. velocities
c. wavelengths
d. both a and c

C. Answer the following questions orally.

1. When will the temperature of the bath of radiation increase and that of the body decrease?
2. Which character of the surface of a body implies the general rule that a good absorber is a good emitter?
3. What does a black body mean?
4. How will a black body look under outside illumination?
5. At what temperature will a black body give off more thermal radiation than any other hot body?
6. Why is black-body radiation often called cavity radiation?
7. Why does the black body play a preferential role in the study of thermal radiation?
8. In what way(s) will the Second Law of Thermodynamics help the study of black-body radiation?
9. Why are the fluxes emitted by both left and right cavities the same?

Part II. Language Practice

A. Choose a, b, c, or d which best completes each item.

1. The ratio of the total emissive power of .... to the total emissive

power of a perfect black body at the same temperature is referred to as emissivity.

a. a substance
c. a body
b. a form
d. a structure

2. Dull black surfaces have the greatest emissive power .... brightly polished reflecting surfaces have least.

a. although
c. while
b. during
d. as

3. A line spectrum is one in which only certain wavelengths ....

a. seem
c. look
b. appear
d. figure

4. Energy can only exist in the absence of matter in .... of radiant energy.

a. the shape
c. the material
b. the size
d. the form

5. A continuous spectrum is .... in which all wavelengths, between certain limits, are present.

a. single
c. sole
b. only
d. one

6. The nature of electromagnetic radiation depends upon their ....

a. frequency
c. continuance
b. persistence
d. incidence

7. Electromagnetic radiation possessing wavelengths .... those of visible light and those of radio waves are referred to as infrared radiation.

a. above
c. under
b. between
d. inside

8. The fact that heat cannot be transferred by any ...., self-sustaining process from a colder to a hotter body is referred to as the Second Law of Thermodynamics.

a. consecutive
c. continuous
b. successive
d. progressive

B. Fill in the blanks with the appropriate form of the words given.

1. Radiate

a. Black rough surfaces are among the best absorbers of thermal ....

b. A thing .... light, heat, or energy when it sends out or gives out rays of light, heat, or energy.

c. .... energy is the only form in which energy can exist in the absence of matter.

d. .... capture' is a nuclear capture process which results in the emission of gamma rays only.

2. Emit

a. The speed with which electrons are .... from a metal does not depend on the strength of the light.

b. Radioactive .... are very dangerous.

c. The total .... power depends upon the temperature of the body and the nature of its surface.

d. The ratio of the radiant energy emitted by a surface to that emitted by a black body at the same temperature is called ....

3. Equal

a. He .... me in physical strength but not in intelligence.

b. A statement of .... between known and unknown quantities, true only for certain values of the unknown quantities is called mathematical equation.

c. He speaks English and Persian with .... ease.

4. Absorb

a. It was discovered that characteristic X-ray and ultraviolet .... spectra were also formed.

b. The absorptivity is a pure numeric, but is often referred to as '.......... power'.

c. When the .... medium is in the solid or liquid state the spectrum of the transmitted light shows broad dark regions which are not resolvable into sharplines.

d. Paper that .... ink is called blotting-paper.

5. Indicate

a. Litmus is red with acids and blue with alkalis, a change in color .... that neutralization is complete.

b. Is a high forehead .... of great mental power?

c. There was not much .... that next few years would be peaceful.

d. Litmus paper .... the presence or absence of acids in a solution.

6. Intensify

a. The thickening or increasing of the opacity of the film of a negative is an example of ....

b. In order to produce a stronger contrast of light and shade the chemically affected parts of a negative were ....

c. The .... of heat is called temperature and can be measured with a thermometer.
d. Energy, or heat, or a feeling is .... when it is strong and powerful.

C. Fill in the blanks with the following words.

temperatures	spectrum	curve
proportional	maximum	prism
wavelength	shifts	hot

If the radiation from a black body is focused on a spectrometer slit, analyzed by a/an .... of fluorite or quartz, and allowed to fall on a sensitive detector which can be moved across the ...., a distribution .... with a well-defined shape is obtained. It has a single maximum, occurring at some .... λ_m. If measurements of the spectrum are made for a series of different ...., and if the detector response (which will be .... to e_λ) is plotted against λ for each temperature, then it is observed (see Figure 6-4), (*a*) that the curves get rapidly higher as T increases, and in accordance, in fact, with the Stefan-Boltzmann law, i.e., $\int_0^\infty e_\lambda \, d\lambda = \sigma T^4$

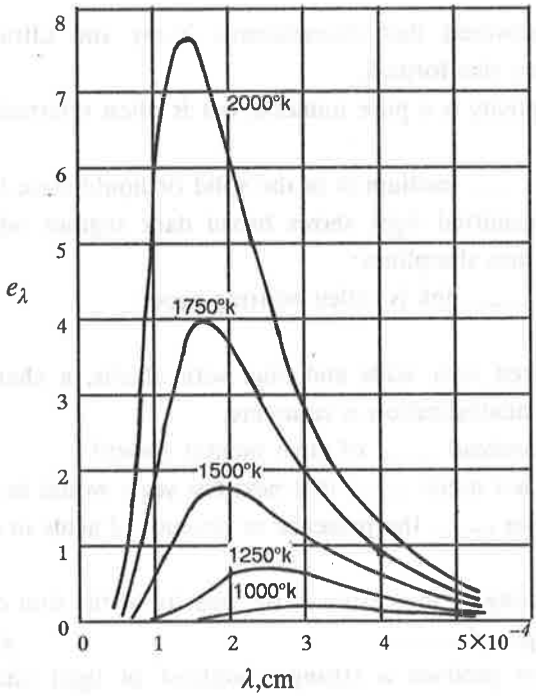


Figure 6-4. The Black-Body Spectrum at Several Temperatures.

(*b*) that the position of the maximum of the curve .... toward shorter wavelengths as T increases. This is already obvious to us if we remember how a/an .... wire, for example, passes from red toward blue heat as its temperature is raised. The exact way in which the .... shifts is very simple; viz.,

$$\lambda_m T = \text{const}$$

D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. However, in the early years of the twentieth century, theoretical and experimental investigations established that light sometimes has particle properties.

b. According to the view of classical physics, light is a wave consisting of electric and magnetic fields with a smooth distribution of energy.

c. According to this new view, light acts like a stream of particlelike energy packets.

d. Further investigations soon established that energy quantization is a pervasive feature of the microscopic world–the energy of atoms and the energy of electrons and other subatomic particles is packaged in energy quanta.

e. The interference and diffraction phenomena give direct experimental evidence for the wave properties of light.

f. These energy packets are called **quanta** of light, or **photons.**

1	2	3	4	5	6

Section Two: Further Reading

More About the Black-Body Radiation

Every substance emits electromagnetic radiation, the character of which depends upon the nature and temperature of the substance. The discrete spectra of excited gases arise from electronic transitions within isolated atoms.

At the other extreme, dense bodies such as solids radiate continuous spectra in which all frequencies are present; the atoms in a solid are so close together that their mutual interactions result in a multitude of adjacent quantum states indistinguishable from a continuous band of permitted energies.

The ability of a body to radiate is closely related to its ability to absorb radiation. This is to be expected, since a body at a constant temperature is in thermal equilibrium with its surroundings and must absorb energy from them at the same rate as it emits energy. It is convenient to consider as an ideal body one that absorbs *all* radiation incident upon it, regardless of frequency. Such a body is called a *black body.*

It is easy to show experimentally that a black body is a better emitter of radiation than anything else. The experiment, illustrated in Figure 6-5, involves two identical pairs of dissimilar surfaces. No temperature difference is observed between surfaces I′ and II′. At a given temperature the surfaces I and I′ radiate at the rate of e_1 W/m^2, while II and II′ radiate at the different rate e_2. The surfaces I and I′ absorb some fraction a_1 of the radiation falling on them, while II and II′ absorb other fraction a_2. Hence I′ absorbs energy from II at a rate proportional to a_1e_2, and II′ absorbs energy from I at a rate proportional to a_2e_1. Because I′ and II′ remain at the same temperature, it must be true that

$$a_1e_2 = a_2e_1$$

and

$$\frac{e_1}{a_1} = \frac{e_2}{a_2}$$

The ability of a body to emit radiation is proportional to its ability to absorb radiation. Let us suppose that I and I′ are black bodies, so that $a_1=1$, while II and II′are not, so that $a_2<1$. Hence

$$e_1 = \frac{e_2}{a_2}$$

and, since $a_2<1$, $e_1>e_2$. A black body at a given temperature radiates energy at a faster rate than any other body.

The point of introducing the idealized black body in a discussion of thermal radiation is that we can now disregard the precise nature of whatever is radiating, since all black bodies behave identically. In the laboratory a black body can be approximated by a hollow object with a very small hole leading to its interior (Figure 6-6). Any radiation striking the hole enters the cavity, where it is trapped by reflection back and forth until it is absorbed. The cavity walls are constantly emitting and absorbing radiation, and it is in the

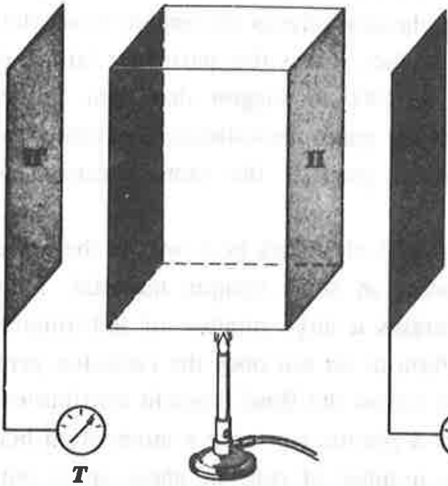


Figure 6-5. Surfaces I and I′ Are Identical to Each Other and Are Different From the Identical Pair of Surfaces II and II′.

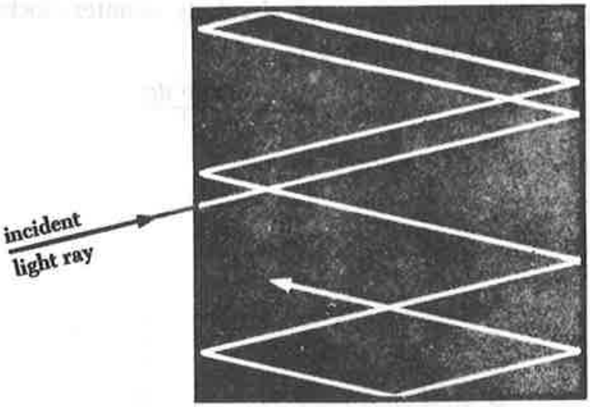


Figure 6-6. A Hole in the Wall of a Hollow Object Is an Excellent Approximation of a Black Body.

properties of this radiation (*black-body radiation*) that we are interested. Experimentally we can sample black-body radiation simply by inspecting what emerges from the hole. The results agree with our everyday experience; a black body radiates more when it is hot than when it is cold, and the spectrum of a hot black body has its peak at a higher frequency than the peak in the spectrum of a cooler one. We recall the familiar behavior of an iron bar as it is heated to progressively higher temperatures: at first it glows dull red, then bright orange-red, and eventually becomes 'white hot'. The spectrum of black-body radiation is shown in Figure 6-7 for two temperatures.

The principles of classical physics are unable to account for the observed black-body spectrum. In fact, it was this particular failure of classical physics that led Max Planck in 1900 to suggest that light emission is a quantum phenomenon. We shall use quantum-statistical mechanics to derive the Planck radiation formula, which predicts the same spectrum as that found by experiment.

Our theoretical model of a black body will be the same as the laboratory version, namely, a cavity in some opaque material. This cavity has some volume V, and it contains a large number of indistinguishable photons of various frequencies. Photons do not obey the exclusion principle, and so they are Bose particles that follow the Bose-Einstein distribution law. The number of states $g(p)$ in which a photon can have a momentum between p and $p+dp$ is equal to twice the number of cells in phase space within which such a photon may exist. The reason for the possible double occupancy of each cell is that photons of the same frequency can have two different directions of polarization (circularly clockwise and circularly counter-clockwise). Hence, using the argument that led to Eq. 6-1.

$$g(p)\,dp = \frac{8\pi V p^2 dp}{h^3} \qquad (6\text{-}1)$$

Since the momentum of a photon is $p=h\nu/c$,

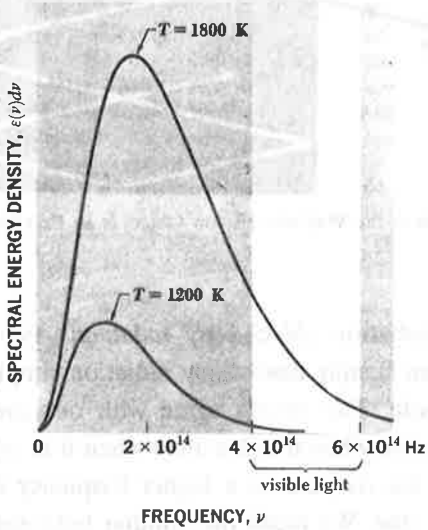


Figure 6-7. Black-Body Spectra. The spectral distribution of energy in the radiation depends only upon the temperature of the body.

$$p^2 dp = \frac{h^3 \nu^2 d\nu}{c^3} \qquad (6\text{-}2)$$

and

$$g(\nu)\ d\nu = \frac{8\pi V}{c^3}\nu^2\ d\nu \qquad (6\text{-}3)$$

We must now evaluate the Lagrangian multiplier α in Eq. 6-2. To do this, we note that the number of photons in the cavity need *not* be conserved. Unlike gas molecules or electrons, photons may be created and destroyed, and so, while the total radiant energy within the cavity must remain constant, the number of photons that incorporate this energy can change. For instance, two photons of energy $h\nu$ can be emitted simultaneously with the absorption of a single photon of energy $2h\nu$. Hence

$$\Sigma\, \delta n_i \neq 0$$

which we can express by letting $\alpha=0$ since it multiplies $\Sigma\, \delta n_i=0$.

Substituting Eq. 6-3 for g_i and $h\nu$ for ε_i, and letting $\alpha=0$ in the Bose-Einstein distribution law (Eq. 6-2), we find that the number of photons with frequencies between ν and $\nu+d\nu$ in the radiation within a cavity of volume V whose walls are at the absolute temperature T is

$$n(\nu)\ d\nu = \frac{8\pi V}{c^3}\frac{\nu^2\ d\nu}{e^{h\nu/kT}-1} \qquad (6\text{-}4)$$

The corresponding spectral energy density $\varepsilon(\nu)\ d\nu$, which is the energy per unit volume in radiation between ν and $\nu+d\nu$ in frequency, is given by

$$\varepsilon(\nu)\ d\nu = \frac{h\nu n(\nu)\ d\nu}{V}$$

$$= \frac{8\pi h}{c^3}\frac{\nu^2\ d\nu}{e^{h\nu/kT}-1} \qquad \text{Planck radiation formula} \qquad (6\text{-}5)$$

Eq. 6-5 is the *Planck radiation formula,* which agrees with experiment.

Two interesting results can be obtained from the Planck radiation formula. To find the wavelength whose energy density is greatest, we express Eq. 6-5 in terms of wavelength and set

$$\frac{d\varepsilon(\lambda)}{d\lambda} = 0$$

and then solve for $\lambda=\lambda_{max}$. We obtain

$$\frac{hc}{kT\lambda_{max}} = 4.965$$

which is more conveniently expressed as

$$\lambda_{max}T = \frac{hc}{4.965k} \quad (6\text{-}6)$$
$$= 2.898\times10^{-3} \text{ m K}$$

Eq. 6-6 is known as *Wien's displacement law*. It quantitatively expresses the empirical fact that the peak in the black-body spectrum shifts to progressively shorter wavelengths (higher frequencies) as the temperature is increased.

Another result we can obtain from Eq. 6-5 is the total energy density ε within the cavity. This is the integral of the energy density over all frequencies,

$$\varepsilon = \int_0^\infty \varepsilon(\nu)\, d\nu$$
$$= \frac{8\pi^5k^4}{15c^3h^3}T^4$$
$$= aT^4$$

where a is a universal constant. The total energy density is proportional to the fourth power of the absolute temperature of the cavity walls. We therefore expect that the energy e radiated by a black body per second per unit area is also proportional to T^4, a conclusion embodied in the *Stefan-Boltzmann law:*

$$e = \sigma T^4 \quad (6\text{-}7)$$

The value of Stefan's constant σ is

$$\sigma = 5.67\times10^{-8} \text{ W/m}^2 \text{ K}^4$$

Both Wien's displacement law and the Stefan-Boltzmann law are evident in qualitative fashion in Figure 6-7; the maxima in the various curves shift to higher frequencies and the total areas underneath them increase rapidly with rising temperature.

Beiser, A. (1973: pp. 304-309).

Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The temperature of a substance has no bearing on the character of electromagnetic radiation it emits.

.... 2. Usually discrete spectra arise from solids.

.... 3. All frequencies are not present in the discrete spectra.

.... 4. The ability of a body to absorb radiation is related to its ability to emit it.

.... 5. The surface of a hot black body emits less radiation than that of any other hot body at the same temperature.

.... 6. Different black bodies behave differently.

.... 7. The results of laboratory experiments with a black body have nothing to do with our everyday experiences.

.... 8. The exclusion principle governs the behavior of the photons mentioned in the experiment.

B. Choose a, b, c, or d which best completes each item.

1. The multitude of indistinguishable adjacent quantum states in a solid result from the fact that ....

a. spectra are discrete
b. atoms are isolated from each other
c. spectra are continuous
d. atoms are close together

2. When a body is in a thermal equilibrium, ...

a. it absorbs energy faster than it emits it
b. its absorptive characteristics are lower than its emissive characteristics
c. it absorbs energy at the same rate as it emits it
d. its absorptive and emissive characteristics are not equal

3. A hot black body emits .... anything else.

a. more radiation than
b. same amount of radiation as
c. less radiation than
d. uncomparable amount of radiation as

4. An iron bar being heated increasingly to a higher temperature, finally becomes ....

a. yellow
b. red
c. orange-red
d. white

5. The spectrum of a hot black body ....

a. arisen from electronic transitions within isolated atoms is discrete
b. is continuous in certain frequencies and discrete at others
c. has its peak at a higher frequency than the peak in the spectrum of a cooler one
d. can be explained by the principle of smooth distribution of energy of the classical physics

6. The character of electromagnetic radiation emitted from every substance depends on its ....

a. nature
b. intensity
c. temperature
d. both a and c

C. Write the answers to the following questions.

1. Why does a black body radiate energy faster than any other body at a given temperature?
2. Why are the principles of classical physics unable to account for the black-body spectrum?
3. Why did Max Planck suggest that light emission is a quantum phenomenon?
4. What kind of spectrum is predicted by the Planck radiation formula?
5. What kind of material is used in the theoretical model of a black body?
6. What is the name of the scientific law which expresses that the peak in the black-body spectrum shifts to higher frequencies as the temperature increases?
7. Which law does the photons mentioned in the experiment obey?
8. What is the reason for the possible double occupancy of each cell?
9. Why can the number of photons that incorporate the total radiant energy change?

❂ ❂ ❂

Section Three: Translation Activities

A. Translate the following passage into Persian.

Adiabatic Expansion

Wien considered a reversible adiabatic expansion of a cavity containing radiation. Such an expansion reduces the total energy of the cavity (because external work has been done) and also shifts its radiation spectrum toward longer wavelengths. If we imagine the radiation (in equilibrium with its enclosure) as constituted of standing waves, it is plausible that the increase of linear dimension l of the cavity should be accompanied by a 'stretching' of the radiation wavelengths λ in such a way that the general pattern of standing waves in the cavity remains unaffected. This will be true if we put $\lambda_1/\lambda_2=l_1/l_2$. Corresponding wavelength *intervals* are similarly defined by $d\lambda_1/d\lambda_2=l_1/l_2$. That this relation between corresponding wavelengths does in fact hold good was shown by Wien to follow from the Doppler shift for reflection of the radiation at the walls of the expanding enclosure. The amount of the shift is shown to remain the same, even when the expansion is made to take place infinitely slowly. It thus becomes possible to discuss the expansion as a reversible thermodynamic process, in which the temperature of the radiation falls from T_1 to T_2.

This time we restrict attention to the radiation within a small wavelength range. We introduce the energy density *per unit wavelength* $u(\lambda)$. Then we are interested in an amount of energy $u(\lambda_1)\, d\lambda_1$ in the initial state and the corresponding (but not equal) amount $u(\lambda_2)\, d\lambda_2$ in the final state.

B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. adiabatic ....
2. black-body radiation ....
3. cavity radiation ....
4. dense body ....
5. emitter of radiation ....
6. energy flux ....
7. energy quanta ....
8. energy quantization ....
9. equilibration ....
10. exclusion principle ....
11. fluorite ....
12. hot body ....
13. Lagrangian multiplier ....
14. linear dimension ....
15. momentum ....
16. quantum-statistical mechanics ....
17. quartz ....
18. radiant heat ....
19. radiative heat transfer ....
20. spectral emittance ....
21. spectral energy density ....
22. spectrometer ....
23. subatomic particle ....
24. thermal equilibrium ....
25. thermal radiation ....
26. unit frequency interval ....
27. wavelength interval ....
28. Wien displacement law ....

Unit 7

Section One: Reading Comprehension

Quantum Mechanics

A physicist is concerned with two worlds: a real external world, which is believed by physicists to have an objective reality, and an image of this world, an internal world, which he hopes is a reasonable model of the external world. The external world manifests itself through sense impressions; from birth, and indeed even before, the human brain is bombarded with data resulting from the stimulation of the sense organs by this external world. At first, these data represent a hopeless jumble, but gradually the brain correlates various data and begins remembering basic correlation patterns. Slowly a correlation structure evolves. The recurrence of such correlation patterns in the sense data gradually becomes interpreted as evidence of a real external world.

By the time adulthood is reached, the picture of the external world obtained in this way has taken on such an apparently real and permanent form that it is difficult to believe that it is in fact just a picture. This internal picture, or model, of the external world may, of course, be as much conditioned by the nature of the human mind as by the nature of the external world. It is clearly affected by the limitations of the sense organs, and it may also be affected by the form of the brain, with its computer-type switching mechanisms. It seems reasonable to assume that a brain capable of an 'on-off' type of digital reasoning will construct with ease a model such that a particle is either at a certain point in space or else not; it may have difficulty with a model for which the particle is neither there nor not there.

The difficulty with such a primitive concept as that of a particle which always possesses some definite position and velocity is that it is a generalization which has grown out of very crude, large-scale observations. A flying bird, or a thrown stone, can apparently be characterized by a trajectory. However, definite position and velocity at each instant of time are properties of the model only: the position and velocity are always determined observationally in only a rough manner.

Mechanics is the branch of physics dealing with the effects of forces on the motions of bodies. In what is known as the *classical* picture, the world is composed of distinct elements, each possessing a definite position and velocity. These elements, or particles, interact with one another via forces which, in principle at least, can be completely known and whose effects can be allowed for exactly in predicting the motions of the various interacting bodies. Classical mechanics is a computational scheme, based on Newton's famous laws of motion, for describing the motions of bodies in terms of given initial conditions by specifying the positions and velocities of all bodies as functions of time. Despite the many successful applications of classical mechanics to a wide range of physical phenomena, it was apparent at the beginning of the present century that not all of the then-known phenomena could find their explanation in classical mechanics and classical electromagnetic theory. To meet the challenge of these classically inexplicable observations, a completely new system of dynamics, quantum mechanics, was developed.

While there are many analogies and formal parallels between classical and quantum mechanics, the basic underlying assumptions of quantum theory are radically different from those of classical mechanics and may be considered to constitute a fundamentally different way of looking at nature. That is, the quantum model, or picture, of the world is radically different from the classical model. It should be emphasized at the start that one could no more 'derive' quantum mechanics than one can derive Newton's laws of motion. Instead, quantum mechanics was developed on the basis of assumptions and postulates which were arrived at on the basis of intuition and analogy with classical concepts, and the predictions based on the *postulated* formalism were compared with observations of the external world. It is a tribute to the genius of the formulators of quantum theory that they were able to devise a scheme for predicting the behavior of physical systems that has stood the test, not only of experimental observations explicable within the scope of classical mechanics, but also of many others that clearly indicate the inadequacy of classical theory.

A basic concept of mechanics is that of an *observable,* that is, an aspect or parameter of a system that is at least in principle directly measurable. One of the fundamental differences between classical and quantum theory is that, in quantum mechanics, *not all observables can be measured with arbitrary accuracy at the same time,* whereas the contrary is true in classical mechanics. The act of measuring the value of any observable disturbs the system in such a way that some *other* observable is altered in value. The difference between the classical and quantum assumptions regarding this is that classically the effects of the disturbance due to the measurement can be exactly allowed for in predicting the future behavior of the system, whereas quantum-mechanically the exact effects of the disturbance accompanying any measurement are *inherently* unknown and unknowable. Thus, a measurement of the position of a particle introduces an unpredictable uncertainty regarding its momentum. If such a situation exists, the whole concept of trajectory clearly must be re-examined, as this classical concept can then lose much, if not all, of its significance.

Dicke, R. H., & Wittke, J. P. (1964: pp. 1-3).

Part I. Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The sense data is systematic and has correlation patterns from the very beginning.

.... 2. The special structure of the brain affects the sense data.

.... 3. Newton's laws of motion form the basis of the classical mechanics.

.... 4. According to classical mechanics, all observables can be measured accurately.

.... 5. The momentum of a particle is affected by the act of measuring its position.

.... 6. Quantum and classical mechanics both look at the nature basically in the same way.

.... 7. Experimental tests have proved the validity of the assumptions of the quantum mechanics.

.... 8. The model constructed by the brain is capable of accounting for particles which are present and absent at the same instant of time.

B. Choose a, b, c, or d which best completes each item.

1. All of the following are likely to affect the picture of the external world except ....

a. the nature of human mind

b. the limitations of the sense organs

c. the 'on-off reasoning mechanism of the brain

d. the nature of the external world

2. The main idea of the first paragraph is that ....

a. a physicist is primarily concerned with making reasonable models of the external world

b. according to physicists, even the internal world has an objective reality

c. a physicist usually attempts to correlate the sense impressions with the external world

d. according to physicists, the external world is the result of correlation of sense data by the brain

3. The problem with the picture of the external world formed in the mind is that it ....

a. does not evolve after the adulthood

b. can only be explained by the classical mechanics

c. does not take into account the nature of the human mind

d. is based on rough general observations

4. The classical mechanics is incapable of ....

a. explaining completely known forces

b. describing motions of bodies as functions of time

c. accounting for elements with indefinite position

d. predicting the motions of different interacting particles

5. According to quantum mechanics, ...

a. it is possible to measure a parameter of a system

b. the disturbances resulting from measurements are knowable

c. it is impossible to measure all observables

d. the future behavior of a system can be predicted

6. Quantum mechanics differs from classical mechanics in that the former ....

a. is based on analogy, but the latter is based on intuition

b. makes use of observable facts, but the latter depends on postulates

c. is based on assumptions, but the latter is not

d. is capable of providing an internal picture of the world, but the latter is not

C. Answer the following questions orally.

1. What is the most important difference between classical and quantum mechanics?
2. How do we perceive the external world?
3. How does the brain organize the sense data?
4. Which factors affect the picture of the external world?
5. Which kind of mechanics is more elaborate and theoretically more powerful?
6. What role do postulates play in quantum mechanics?
7. How can a particle be measured without disturbing its velocity?

Part II. Language Practice

A. Choose a, b, c, or d which best completes each item.

1. The classical concept of .... of a particle having some definite position and velocity is referred to as trajectory.
   a. the road c. the course
   b. the lane d. the path
2. Parameters of a system that are .... measurable are called observables.
   a. directionally c. directly
   b. northerly d. pointedly
3. The new system of dynamics which is .... explaining all observables is called quantum mechanics.
   a. capable of c. competent in
   b. proficient in d. able at
4. Classical mechanics can .... the velocities of all distinct elements.
   a. mention c. specify
   b. name d. substantiate
5. Assumptions of quantum mechanics are .... referred to as postulates.
   a. ordinarily c. regularly
   b. rarely d. usually
6. The act of measuring the value of any aspect of a system will .... the system.
   a. agitate c. disturb
   b. confuse d. interrupt

B. Fill in the blanks with the appropriate form of the words given.

1. Condition

a. These are the owner's .... for allowing the students to use the rooms.

b. Your admission to the college is, of course, ... on the fulfillment of certain requirements.

c. We will never .... the workers to a willing acceptance of a wage.

d. He has been released from the prison ....; he is not supposed to leave Berlin and its environs.

2. Interpret

a. A correct .... of something, e.g., of a table of figures, is made by someone who possesses the key, code, or information which actually applies to it.

b. We can only .... gestures correctly if we are familiar with the customs and conventions of the communities which use them.

3. Reason

a. Students in a hostel can .... expect to be given good food most of the time.

b. A .... price for an article is one which an average person can be expected to pay.

c. An acceptable offer is one which a sensible person would have a good .... for accepting under normal circumstances.

d. She .... with me for an hour about the folly of my plans.

4. Stimulate

a. Communication begins when one organism produces a .... intentionally.

b. His father always .... him to further efforts.

c. Athletes are not supposed to take .... drugs before any contest.

5. Impress

a. A general .... sometimes unconsciously takes account of important factors which are not taken into account by an analysis.

b. In ordinary life, we are .... by a book, a film, etc., when it leaves a strong effect on us.

c. She has been invited to an .... ceremony.

d. The speech was made so .... that everybody was moved.

6. Evolve

a. Some scientific thinkers approach the problems of .... in a different way, and their views are in some respects in conflict with Darwin's.

b. In the earlier part of its history, technology .... almost independently of science.

c. Some theories or concepts seek to explain various features of the .... stages in development from less to greater complexity.

C. Fill in the blanks with the following words.

interpretation	formalism	beyond
experience	embodies	data
historical	ultimate	led

At the present stage of human knowledge, quantum mechanics can be regarded as the fundamental theory of atomic phenomena. The experimental

.... on which it is based are derived from physical events that lie almost entirely .... the range of direct human perception. It is not surprising, therefore, that the theory .... physical concepts that are foreign to common daily .... These concepts did not appear in the .... development of quantum mechanics, however, until a quite complete mathematical .... had been evolved. The need for quantitative comparison with observation, which is the .... test of any physical theory, in this case .... first to the formalism and only later to its .... in physical terms.

D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. The energy levels of the system are also found in the process of solving its Schrödinger equation.

b. The systematic study of the mechanics of particles in the quantum domain is called **quantum mechanics.**

c. Schrödinger's equation is to quantum mechanics what Newton's laws of motion are to Newtonian mechanics.

d. Then information about the behavior of the particle is extracted from the wave functions.

e. Like Newton's laws, Schrödinger's equation was constructed on the basis of postulates designed to ensure its agreement with a few key phenomena, and it was subsequently found capable of explaining a very large number of other phenomena.

f. For instance, by squaring the wave function the probability density is obtained, and this quantity determines where the particle is likely to be found in a measurement of its position.

g. These explanations are obtained by solving the equation in the particular form that it assumes in a given system, thereby finding the wave functions associated with the particle of the system in its various quantum states.

1	2	3	4	5	6	7

Relativity With Respect to the Means of Observation as the Basis for the Quantum Way of Describing Phenomena

The new, quantum manner of describing phenomena must allow for the possibility of actual measurement of the properties of a micro-object. We must not ascribe to any object properties and states of motion that cannot be justified. For this reason particular attention should be given to the way in which we specify properties and states of motion. We must bear in mind the design and operation of the instruments that create the conditions to which the object is subjected. As has been said, the instruments and the external conditions must be described in the classical manner by indicating their parameters. It stands to reason that these parameters can be defined only to an accuracy permitted by the uncertainty relations. Otherwise we will be exceeding the actual potential of the measuring instruments.

A micro-object is revealed in its interaction with an instrument. For instance, the path of a charged particle becomes visible in the irreversible snowballing process that takes place in a cloud chamber or in the emulsion of a photographic plate (the particle loses its energy in ionizing the vapour or the chemicals of the emulsion; hence, its momentum becomes uncertain). The results of the interaction of an atomic object with a measuring instrument (which is described classically) are the main experimental elements the systematization of which, based on the assumptions about the properties of the object, makes up the aim of the theory: from a study of such interactions we can deduce the properties of the atomic object, and the predictions of the theory are formulated as the expected results of these interactions.

Such a statement of the problem allows the introduction of quantities that characterize the object irrespective of the measuring instrument (electric charge, mass, and properties described by quantum mechanical operators) and at the same time makes possible a comprehensive approach to the object: the object can be viewed from the aspect (wave or corpuscular, for instance) necessitated by the instrument and by the external conditions the instrument creates.

The new statement of the problem makes it possible to consider the case when the various aspects and properties of an object do not manifest themselves simultaneously, that is, when *particularization of the object's behaviour* is impossible. This will be so if incompatible external conditions are needed for the manifestation of the object's properties (for instance, wave and corpuscular).

We can act on the proposal of Niels Bohr and call *complementary* the properties that reveal themselves in their pure form only in different experiments held in mutually exclusive conditions, whereas in conditions of one and the same experiment they manifest themselves only in an incomplete, modified form (for instance, the incomplete localization in the coordinate and the momentum space permitted by the uncertainty relations). There is no sense in considering complementary properties simultaneously (in the pure form), which explains the absence of a contradiction in the concept of wave-corpuscular duality.

By making the results of the interaction of a micro-object and a measuring instrument the basis of the new manner of description we introduced an important concept, the concept of *relativity with respect to the means of observation,* which generalizes the well-known concept of relativity with respect to the frame of reference. Such a manner of description does not at all mean that we are ascribing a lesser degree of reality to the micro-object than to the measuring instrument or that we are reducing the properties of the micro-object to the properties of the instrument. On the contrary, a description on the basis of the concept of relativity with respect to the means of observation gives a much deeper, more refined, and more objective picture of the micro-object than was possible on the basis of the idealizations of classical physics. Such a picture also requires a more sophisticated mathematical apparatus, namely, the theory of linear operators, including eigenfunctions and eigenvalues, the theory of groups, and other mathematical concepts. The use of this apparatus in quantum physics made it possible to give a theoretical explanation of some fundamental properties of matter that could not be explained in the classical way and also to calculate the values of many quantities observed in experiments (for instance, the frequencies in atomic spectra). But more than that–and this is no less important to us–the physical interpretation of the mathematical concepts used in quantum mechanics leads to a number of profound and principled conclusions; for one, generalization of the concept of the state of a system on the basis of the concepts of probability and potential possibility.

Fock, V. A. (1982: pp. 17-19).

Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The operation of the measuring instrument creates the conditions to which an object is subjected.

.... 2. The calculation of the frequencies in atomic spectra was made possible by a theoretical explanation.

.... 3. The path of a charged particle that loses its energy in ionizing the vapour is visible.

.... 4. The properties of an atomic object can be deduced from the interaction of the object and the measuring instrument.

.... 5. The incomplete and modified properties of an object are complementary.

.... 6. The interaction between an atomic object and a measuring instrument is the source of error.

.... 7. Quantum mechanics reduces the properties of a micro-object to the properties of the instrument.

.... 8. Classical physics gives a refined and objective picture of a micro-object.

B. Choose a, b, c, or d which best completes each item.

1. The actual potential of the measuring instruments are affected by ....
   a. the possibility of actual measurement
   b. the object properties and states of motion
   c. the specification of the states of motion
   d. the accuracy permitted by the uncertainty relations
2. The particularization of an object's behaviour is impossible when ....
   a. wave and corpuscular properties of the object are not known
   b. unjustifiable properties are ascribed to the object
   c. the object loses its energy in ionizing the vapour
   d. different aspects of the object do not manifest themselves simultaneously
3. There will be no contradiction in the concept of wave-corpuscular duality if ....
   a. complementary properties are not considered simultaneously
   b. only the pure form of the properties is used exclusively
   c. the measuring instruments do not create incomplete condition
   d. particularization of the concept can be made accurately

4. The concept of relativity with respect to the means of observation ....
   a. ascribes a lesser degree of reality to the micro-object
   b. reduces the properties of the micro-object to that of the instrument
   c. provides a more accurate picture of the micro-object
   d. excludes the possibility of using the theory of linear operators
5. The aim of the new quantum theory is ....
   a. to reveal the interaction of a micro-object with an instrument
   b. to emulate the chemicals of a photographic plate
   c. to reverse the path of a charged particle in order to make it visible
   d. to systematize the interaction of an atomic object with a measuring instrument
6. The introduction of the characteristic quantities of an object irrespective of the measuring instrument is made possible by statement such as ....
   a. the path of a charged particle becomes visible in the irreversible snowballing process that takes place in a cloud chamber
   b. the results of the interaction of an atomic-object with a measuring instrument are based on the assumptions about the properties of the object
   c. the emulsion of a photographic plate makes the deduction of the properties of the object possible
   d. the systematization of the main experimental elements according to the classical mechanics is not attainable

C. Write the answers to the following questions.

1. What made the calculation of the values of many quantities possible?
2. What is the role of the concept of relativity in the generalization of the concept of the state of a system?
3. Why are the design and operation of the instruments important for the quantum mechanics?
4. What is the aim of the systematization of the quantum theory?
5. What role do the assumptions about the properties of an object play in the quantum theory?
6. When do the various properties of an object manifest themselves simultaneously?
7. What kind of description gives an objective picture of a micro-object?
8. What kind of description needs the theory of linear operators?

Section Three: Translation Activities

A. Translate the following passage into Persian.

Potential Possibility in Quantum Mechanics

If we take the act of interaction between an atomic object and a measuring instrument as the source of our judgements about the object's properties and if in studying phenomena we allow for the concept of relativity with respect to the means of observation, we are introducing a substantially new element into the description of the atomic object and its state and behaviour, that is, the idea of probability and thereby the idea of potential possibility. The need to consider the concept of probability as a substantial element of description rather than a sign of incompleteness of our knowledge follows from the fact that for given external conditions the result of the object's interaction with the instrument is not, generally speaking, predetermined uniquely but only has a certain probability of occurring. With a fixed initial state of the object and with given external conditions a series of such interactions results in a statistics that corresponds to a certain probability distribution. This probability distribution reflects the potential possibilities that exist in the given conditions.

Let us consider an experiment with a physical system that would enable us to make predictions about the results of future interactions between the system and measuring instruments of various kinds. Such an *initial experiment* must include a certain *preparation of the system* (for instance, preparation of a monochromatic beam of electrons) and the creation of certain external conditions in which the system will be placed after the preparation (for instance, the passage of the electron beam through a crystal). At times it is advisable to consider the preparation of the system and the creation of external conditions as two different stages of the experiment, but the two stages can also be considered one initial experiment, the purpose of which is to obtain predictions.

B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. arbitrary accuracy ....
2. atomic spectra ....
3. charged particle ....

4. cloud chamber ....
5. computational scheme ....
6. corpuscular ....
7. digital reasoning ....
8. eigenfunction ....
9. eigenvalue ....
10. electric charge ....
11. emulsion ....
12. linear operators ....
13. mass ....
14. mathematical apparatus ....
15. measuring instrument ....
16. micro-object ....
17. monochromatic beam ....
18. motion of bodies ....
19. observable ....
20. photographic plate ....
21. postulated formalism ....
22. potential possibility ....
23. probability ....
24. probability density ....
25. quantum mechanics ....
26. snowballing process ....
27. trajectory ....
28. velocity ....
29. wave function ....

Section One: Reading Comprehension

Elementary Particles

The oddly-named quark was thus christened by one of the originators of the quark theory, Murray Gell-Mann. The quark is one of the particles thought to be 'elementary' at present, and it still has not escaped the realm of fiction completely. The words 'elementary particles' refer to the most fundamental constituents of matter. When I say that the quark has not escaped the realm of fiction, I am being very careful, and conservative since the quark theory can explain all phenomena known at present. What I mean is that we have not reached the stage, as we have with protons and electrons for example, where we have absolutely no doubt about the existence of the quark.

Why is there this slight doubt? It is because, although the quark is supposed to have characteristics unseen in the known particles, no one has spotted anything that looks like it. It appears that one cannot take a quark out of matter and confirm its characteristics. On the contrary, other known particles can be taken out by themselves and measurements can be made on them. Nucleons and electrons were mere theoretical constructs based on conservation laws and so forth at first, but they were eventually isolated and their masses and charges were measured.

Actually, the quark, if it existed by itself, should be very easy to identify. This is because the electric charge carried by the quark is supposed to be two-thirds or one-third of the unit charge, i.e., the charge carried by an electron or a proton. All elements known up to now, be they electrons or nuclei, have electric charges either zero or an integer multiple (±1, ±2, . . .) of the unit charge e carried by an electron. So no matter what piece of matter is examined, its total charge is always an integer multiple of e.

One other important thing is the law of conservation of charge. Although reactions occur among particles and one particle can change into another, or particles exchange their electric charges, the total number of charges never changes. This is a typical example of the conservation laws I mentioned above, and if this is true it is not hard to imagine an element that carries the smallest possible amount of charge. But there is not just one kind of element that carries the smallest charge. Electrons, protons and many others s that differ in mass and other characteristics have the electric charge ±e.

It is theorized that, against the norm, valid for all known particles, quarks have the unprecedented charge of ±e/3 or ±2e/3. That is to any, the ultimate unit of charge is not e but ±e/3. If that is the case, are those particles that carry charge ±e such as electrons and protons not elementary particles but compounds made of quarks?

The answer is this: The proton is indeed a compound particle made of three quarks. In fact the quark theory grew out of conceiving the proton to be a compound particle. On the other hand, the electron is not made of quarks and is still thought to be elementary.

I stated before that the leptons and quarks are the fundamental particles; the electron is one of the leptons. The name 'lepton' comes from Greek meaning light particle. Among the other leptons are neutrinos (ν) and muons (μ), but leptons other than electrons usually do not appear in everyday phenomena. In any case, the electric charge of a lepton is ±e or 0.

What is the 'heavy' particle as opposed to the light lepton? The Greek word for it is 'baryon', and both protons and neutrons belong to this group. As is well known, the proton, or the hydrogen nucleus, has a mass some 1,800 times that of the electron. The neutron (n) is also a baryon, and several protons and neutrons congregate to make up an atomic nucleus; the nucleus pulls a cloud of electrons around itself to make up a neutral atom.

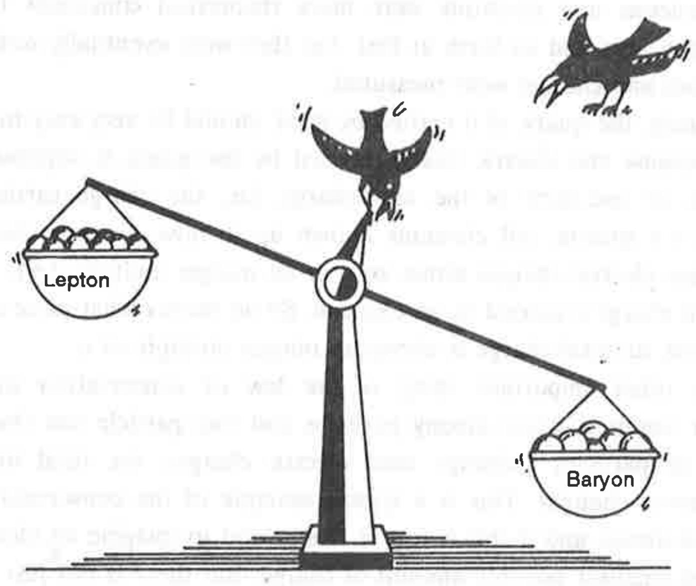


Figure 8-1. Baryon (Heavy Particle) and Lepton (Light Particle).

Protons and neutrons, as they are the ingredients of the nucleus, are collectively called nucleons (N). Other than these nucleous, baryons include the lambda particle (A), sigma particle (Σ), and other unstable heavy particles. These baryons are now thought to be not fundamental particles but made of three quarks.

In between the baryons and the leptons, there exist 'mesons' or 'middle particles'. These include the pion (π) whose existence was first predicted by Dr. H. Yukawa. As befits the name meson, the mass of the pion is 270 times that of the electron and one-seventh that of the proton.

Nambu, Y. (1985: pp. 10-12).

Part I. Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. Most of the known particles can be isolated and measured.

.... 2. The existence of protons and electrons has been verified both theoretically and experimentally.

.... 3. The conservation laws played no role in the identification of electrons.

.... 4. Proton and electron both are regarded as being elementary particles.

.... 5. All of the leptons can be found in ordinary phenomena.

.... 6. An atomic nucleus is made up of the combination of several neutrons and protons.

.... 7. Protons and neutrons are made up of three quarks.

.... 8. Despite the fact that an electron is not made up of quarks, it is still treated as being one of the elementary particles.

B. Choose a, b, c, or d which best completes each item.

1. Theoretically, it is believed that the quark has an abnormal electric charge of ....

a. ±e c. ±2

b. ±1 d. ±e/3

2. The quark differs from other particles in that it ....

a. is just a theoretical concept

b. does not remain the same after any reaction

c. is made up of unchanging elements

d. cannot be taken out of matter

3. All of the following except .... are heavy particles.
   a. proton   c. pion
   b. neutron   d. nucleon
4. Baryons have much more .... than leptons.
   a. electric charge   c. electromagnetic force
   b. mass   d. velocity
5. All of the following except .... are fundamental light particles.
   a. muons   c. electrons
   b. neutrinos   d. protons
6. At the present state of knowledge, a physicist cannot be hundred percent sure that .... exists.
   a. electron   c. proton
   b. neutron   d. quark
7. All of the elements identified so far are distinguishable from the quark in that ....
   a. the formers are made from electrons and protons, but the latter is made up of nuclei
   b. the philosophy of natural sciences which demand verification applies to the formers, but not to the latter
   c. the formers have a total charge of an integer multiple of e, but the latter has an electric charge of 1/3 of e
   d. the formers have shapes and seem to have internal structure, but the latter does not

C. Answer the following questions orally.

1. What is the nucleus made up of?
2. What is the role of proton in the quark theory?
3. What makes the existence of the quark uncertain?
4. Which particles are believed to be the fundamental particles?
5. Why is it hard to extract a quark out of matter and measure it?
6. What are some of the unknown mysteries about elementary particles?
7. What is the difference between the electric charge of the quark and other known elements?
8. How much electric charge does a quark have in comparison with electron?
9. What is the normal amount of electric charge for all elements identified so far?

Part II. Language Practice

A. Choose a, b, c, or d which best completes each item.

1. The collective .... used to refer to nucleons and hyperons is baryon.
   a. denomination c. designation
   b. call d. name
2. Electrons, muons, and neutrinos are .... referred to as lepton.
   a. assembly c. congregately
   b. collectively d. exactly
3. One of the three .... elementary particles which have been postulated by M. Gell-Mann as the basis of all matter is quark.
   a. conditional c. typical
   b. practical d. hypothetical
4. The principle according to which the total electric charge associated with a system .... constant is called conservation of charge.
   a. survives c. remains
   b. rests d. settles
5. The group of unstable .... particles with rest masses between those of the electron and the proton are called mesons.
   a. rudimentary c. elementary
   b. introductory d. primary
6. The idea of elementary particles is still somewhat ...., recent work having suggested that protons and neutrons are not indivisible units, but composite entities consisting of a core of unknown origin surrounded by a cloud of mesons.
   a. shapeless c. indistinct
   b. indefinite d. vague

B. Fill in the blanks with the appropriate form of the words given.

1. Eventually
   a. The writer predicted the .... decay and downfall of industrial society.
   b. We hope that .... these struggles and quarrels will be forgotten and peaceful relationships will prevail.

2. Fundamentally
   a. The new treatment is likely to produce a .... improvement in the condition of children suffering from prolonged malnutrition.
   b. The results of these experiments do not .... affect the theory.
   c. It is speculated that the .... of the sect will result in its downfall.

3. Slightly

a. The new calculation is .... different from the earlier one.

b. This year there was a .... increase in production.

c. She felt .... because no one spoke to her.

d. You should not be deceived by the .... of difficulty, the problem is a major one.

4. Typically

a. The establishment of large towns and cities is a .... feature of civilization.

b. Competitive trades in capitalist economies .... spend considerable sums of money on advertisements.

c. An insufficient supply of trained engineers .... the underdeveloped countries.

5. Absolutely

a. I am not .... convinced that the job will suit me.

b. You have .... freedom to do whatever you wish.

6. Sufficiently

a. Is there .... food for the long journey?

b. It has been reported by the ministry of petroleum that there is a .... of fuel for the next winter.

c. We saw .... to account for the noise.

d. Your word will be ...., I am content to accept your promise.

C. Fill in the blanks with the following words.

antiparticle	affirmative	identical
fundamental	positron	heavy
particle	present	mass

The increase in the experimental knowledge concerning fundamental particles has also been very large during the past three or four decades. In 1928, it was thought that only two .... particles existed in nature, the light negative electron and the .... positive proton. In 1932 and 1933 came the first additions, the neutrino, the neutron, and the positron. The .... had already been predicted by Dirac as the .... to the electron, with opposite charge, but with the same .... and spin? The experimental discovery of the positron raised a new question: Does each .... have an antiparticle? The discovery of the antiproton suggested a/an .... answer. At .... anti-particles to each known particle have been found. (Neutral particles can be .... with antiparticles.)

D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. Out of these multitudes, some of the particles may be more elementary than others.

b. The elementary particles were electrons, protons, and neutrons.

c. At present, the number of 'elementary' particles has exceeded a hundred, rendering the concept almost useless.

d. Now that we have the concept of elementary particles, it is not so easy to decide which bits of matter fall into this category.

e. However, new particles started to emerge from cosmic ray collisions and from experiments using particle accelerators.

f. In the 1930s, physicists had a neat, clean picture.

g. As well as the three more familiar particles mentioned above, there are things called mesons, hyperons, and resonances, which add considerable complications to a simple theory of matter.

1	2	3	4	5	6	7

Section Two: Further Reading

Heavy Particles, Light Particles, In-Between Particles

However, classifying particles by their masses is not really very meaningful. There are many mesons that have masses comparable to those of baryons, and the muon, which is a lepton, has a mass about that of the pion. The recently discovered lepton, the tau (τ) has a mass larger than that of the proton.

The baryons and mesons together are called hadrons. This word means 'strong particle' in Greek and these are thus named because they interact strongly. The force responsible for the strong interactions, or the strong force, is different from electromagnetic or gravitational forces, and the force that binds the nucleus together, or the nuclear force, is one of its manifestations.

The force between two nucleons is thought to arise out of the exchange of mesons among the nucleons; one emits a meson and the other absorbs it. Since the exchange occurs frequently, the nuclear force is stronger than the electromagnetic force.

According to the quark theory, baryons are made of three quarks whereas the mesons are made of two quarks–actually, one quark and one antiquark. This is the first time the word 'anti' has been mentioned: it is a prefix that can be applied to any lepton or a hadron. For every particle there exists its 'antiparticle'. As implied by its name, an antiparticle has opposite signed electric charge and opposite signed other 'quantum numbers' from those of the particle, but they have the same mass. These quantum numbers include numbers that characterize particles such as the strangeness quantum number. The particle-antiparticle pair is like a pair of twins and they are not completely different particles. The antiparticle of the electron, the 'antielectron', is usually called the 'positron' and carries an electric charge +e.

The reason we do not see positrons and antiprotons in everyday life is because when these meet up with their partners, electrons and protons, the particle and the antiparticle combine and disappear, or they 'pair annihilate', and their energies appear as, for instance, photons. Conversely, if one wants to make an antiparticle, it has to be 'pair produced' with its particle. Thus, we often do not distinguish between particles and antiparticles when counting the kinds of particles, and following this convention, we have been including antiquarks when discussing quarks in general.

Why do not the mesons pair annihilate if they are made of a quark and an antiquark? Part of the reason is that there are several kinds of quark, and mesons in general are not made of the same kind of quark pairs; but deeper arguments must be left until later.

Let us summarize the story so far. Hadrons ('strong particle') are a

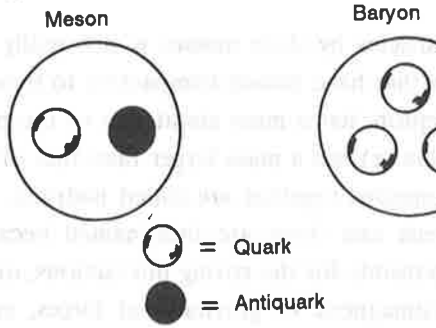


Figure 8-2 Meson and Baryon Contents

group of particles that interact strongly and are made of quarks. Among hadrons, the baryons ('heavy particles') are made of three quarks. (Antibaryons, therefore, are made of three antiquarks.) The mesons are made of two quarks (actually a quark and an antiquark). Other combinations do not seem to exist and, in particular, a single quark has not been observed.

Normally, the substances we observe are made, ultimately, of leptons and quarks. Quarks come together to make baryons, baryons come together to make nuclei, nuclei and electrons come together to become atoms, atoms come together to become molecules, molecules come together to become organisms and so on.

The leptons ('light particles') include such relatively light particles as electrons and neutrinos which do not interact strongly, and these do exist by themselves.

Thus the structure of matter divides into several layers. This means that there are several scales of size and energy. The size scale is obvious. The size of an atom is about 10^{-8} cm, but if we look at its fine details, we will see

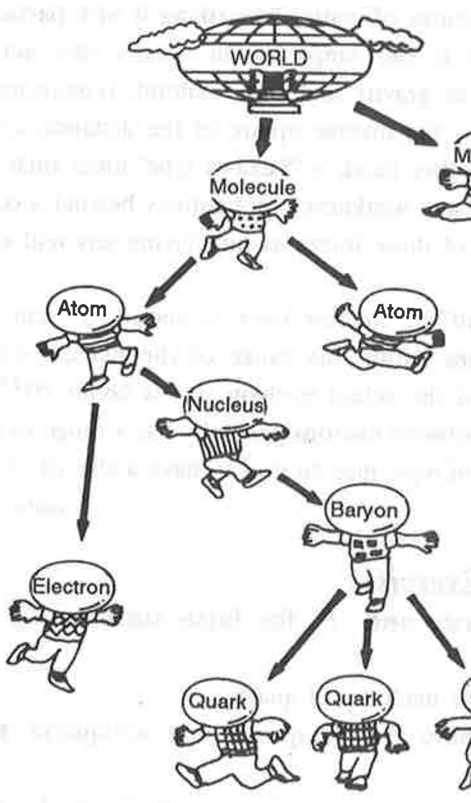


Figure 8-3. Layered Structure of the Material World.

electron clouds around a nucleus which is about 10^{-13} cm. Then if we look at the details of the nucleus, we will find protons and neutrons; and if we look at the details of the nucleons we 'ought' to see the quarks. But when we begin to discuss what we mean exactly by size, all kinds of problems begin to arise.

What Is the 'Size' of a Particle?

One of the problems that arises is the extent of a particle as a 'wave' as dictated by the principles of quantum mechanics. The wave, by its very nature, has an extent but has no set size. But the extent of a wave can be controlled by how one makes a wave. If one wants to confine a wave to a small volume, then it is necessary to choose one made up of short wavelength. Then by the de Broglie relationship which states that the wavelength is inversely proportional to the momentum of a particle, the uncertainty in momentum, and thus the uncertainty in the kinetic energy, becomes large. This is what is known as Heisenberg's uncertainty principle. Since particles with higher energy can be confined in smaller volume, it is necessary to achieve high energies in order to probe the internal structures of matter by striking it with particles.

Another problem is the range of the forces that act between the particles. Forces such as gravity and the Coulomb (electromagnetic) force, whose strength varies as the inverse square of the distance, are said to have infinite range. On the other hand, a 'Yukawa type' force such as the nuclear force has a finite range and weakness exponentially beyond a certain distance; you can actually think of these forces as not having any real effect beyond a certain range.

Since the range of the nuclear force is about 10^{-13} cm, and since the motion of two nucleons within the range of the nuclear force is strongly disturbed, it looks as if the actual nucleon size is about 10^{-13} cm. Since the strong force that acts between hadrons generally has a range of about 10^{-13} cm, all hadrons, regardless of type, may be said to have a size of about 10^{-13} cm.

Nambu, Y. (1985: pp. 12-16).

Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. Nucleons are made up of quarks.

.... 2. Physicists have treated quarks and antiquarks as independent particles.

.... 3. Waves confined to large volume are made up of long wavelengths.

.... 4. Different hadrons such as mesons and baryons all have a quark and an antiquark.

.... 5. High energy particles cannot be confined in small volumes.

.... 6. One of the constituents of atomic nucleus, i.e., a proton/a neutron is called a nucleon.

.... 7. All of the heavy particles or baryons have much more mass than mesons or middle particles.

.... 8. According to de Broglie wavelength, a moving particle, whatever its nature, has wave properties associated with it.

.... 9. Coulomb's law states that the force of attraction or repulsion between two charged bodies is proportional to the magnitude of the charges and inversely proportional to the square of the distance between them.

B. Choose a, b, c, or d which best completes each item.

1. While theoretically possible, the existence of .... in the universe has never been detected.

   a. antiproton c. antimatter
   b. antineutrino d. antineutron

2. Contact between antimatter and matter will result in ....

   a. the combination of both
   b. the creation of an antiproton and a positron
   c. the disappearance of their energies
   d. the annihilation of both

3. Every elementary particle has a corresponding real or hypothetical anti-particle, of ...., with which annihilation can take place.

   a. same electric charge but opposite mass
   b. equal mass but opposite electric charge
   c. same quantum number but different mass
   d. equal magnetic moment but different spin

4. According to ...., it is impossible to determine with accuracy both the position and the momentum of a particle simultaneously.

   a. annihilation radiation c. angular distribution
   b. conservation law d. uncertainty principle

5. Classification of particles by their masses into different classes ....

   a. is based on the Greek classification of particles
   b. although accepted by all physicists yet is not accurate
   c. despite its shortcoming is followed by all physicists
   d. although is not very sensible yet is convenient

6. The force that binds the nucleus together is stronger than the electromagnetic force because ....
   a. its name means strongly interacting particle
   b. the nuclear force is one of its manifestations
   c. it arises out of the frequent exchange of mesons
   d. the strong force in question is different from the gravitational force

C. Write the answers to the following questions.

1. How can the extent of a wave be controlled?
2. Which forces are believed to have infinite range?
3. How does the force between two nucleons arise?
4. How can the internal structure of particles be investigated?
5. What is the order of particles which consecutively make up molecules?
6. What is the reason for the absence of annihilation radiation in mesons?
7. What happens after the particle and antiparticle combine?
8. What is the disadvantage of classifying particles by their masses?
9. Why are all hadrons believed to have a size of about 10^{-13} cm?

Section Three: Translation Activities

A. Translate the following passage into Persian.

Antiparticle

The story of the discovery of elementary particles would not be complete without mention of the antiproton. Until 1957, when the antiproton was observed at the 6 GeV Bevatron at the University of California, the only antiparticle to be positively identified was the positron. It was by no means universally accepted at that time that all particles have an associated antiparticle. In fact, an eminent theoretical physicist had to pay off a 500 dollar bet when Emilio Segré, Owen Chamberlain, Clyde Wiegand and Tom Ypsilantis published their evidence for the antiproton. The Bevatron was designed with this experiment in mind. Older machines could not provide sufficient energy to create this one GeV antiparticle. After bombarding the bubble chamber with high-energy protons, Segré and his co-workers recorded a track which was due to the annihilation of an antiproton-proton pair. The decay products were three or more pions. The amount of energy they carried away from the interaction vertex was equal, within the limits of the experiment, to the combined masses of the annihilated pair.

Physicists now agree with the principle that all particles have an antiparticle with complementary quantum properties, such as opposite electric charge.

B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. antiparticle ....
2. antiquark ....
3. baryon ....
4. bubble chamber ....
5. conservation law ....
6. hadron ....
7. heavy particle ....
8. hyperon ....
9. kinetic energy ....
10. lambda particle ....
11. lepton ....
12. light particle ....
13. meson ....
14. muon ....
15. neutrino ....
16. nucleon ....
17. pair annihilate ....
18. pair produced ....
19. particle accelerator ....
20. pion ....
21. positron ....
22. quantum number ....
23. resonance ....
24. strangeness ....
25. tau ....
26. uncertainty principle ....
27. unit charge ....

Unit 9

Section One: Reading Comprehension

Relativity

In 1905, Einstein made the revolutionary proposal that the contradiction of the invariance of the speed of light in all reference frames is to be resolved by overthrowing the Galilean addition law and the Newtonian concepts of space and time. Einstein was aware of the negative results of the Michelson-Morley experiment, but his real motivation was his firm belief that Maxwell's equations ought to be valid in all reference frames.

Einstein based his Theory of Special Relativity on a general hypothesis concerning all the laws of physics. This hypothesis is the

Principle of Relativity: *All the laws of physics are the same in all inertial reference frames.*

Since the laws for the propagation of light are included in the laws of physics, one immediate consequence of the Principle of Relativity is:

The velocity of light (in vacuum) is the same in all inertial reference frames; it always has the value $c=3.00\times10^8$ *m/s.*

The invariance of the speed of light requires that we sacrifice some of our intuitive, everyday notions of space and time. The fact that a light signal always has a velocity of 3.00×10^8 m/s, regardless of the motion of the source or of the observer, does violence to our intuition. This strange behavior of light is possible only because of a strange behavior of length and time. We should remember that, neither length nor time is absolute–they both depend on the reference frame and suffer contraction and dilation when the reference frame changes.

Since the invariance of the speed of light is of such fundamental significance for the Theory of Relativity, many experimenters have sought to improve the Michelson-Morley experiment, in the hope of detecting some minute effect of the motion of the Earth on the propagation of light. The most precise of the interferometer experiments was that performed in 1930 by G. Joos, who used an interferometer with very long arms carefully isolated against vibrations of the ground. This experiment set a limit of 1.5 km/s on the maximum possible value of the ether wind.

Modern versions of the Michelson-Morley experiment have relied on the comparison of the frequencies of standing waves in two resonant cavities, oriented at right angles. The frequency of such a standing wave is directly proportional to the speed of the wave and inversely proportional to the length of the cavity [$\nu = vn/(2L)$, where n is the number of half-waves in the cavity]. If the two cavities are of identical length, then any observed difference in the frequencies implies a difference in the speeds. An experiment by Jaseja et al. employed lasers as resonant cavities and was able to set an upper limit of 30 m/s on the ether wind. A recent modified version of this experiment by Brillet and Hall employed face-to-face parallel mirrors (Fabry-Perot etalons) as resonant cavities, which were driven by lasers; this experiment was able to set a tighter limit of 15 m/s.

Even more precise results have been obtained by measurements of the Doppler shift between a moving emitter and a receiver of light. According to Newtonian physics, the Doppler shift depends on the velocities of the emitter and the receiver relative to the ether, and therefore it can serve to detect the ether wind. The most precise of the Doppler-shift experiments used γ rays (essentially, short-wavelength X rays) emitted by a sample of radioactive ^{57}Fe. The apparatus of Champeney et al. consists of a turntable, rapidly spinning about its vertical axis (see Figure 9-1). This turntable carries samples of ^{57}Fe on opposite points of its rim. In one of these samples, the iron nuclei are in an excited state of high energy and they emit γ rays by recoilless transitions to states of lower energy. The emission of γ rays without recoil, and therefore without reduction of the γ-ray energy, is called the **Mössbauer effect;** in these emissions the iron crystal absorbs the recoil momentum. These γ rays can be captured by resonant absorption in the other sample of iron. According to Newtonian physics, the Doppler shift between emitter and absorber has one value when they are (instantaneously) on the north-south line, as shown in Figure 9-1; and this Doppler shift has the opposite value one-half rotation later. The mismatch between the emitter and the absorber frequencies would inhibit the resonant absorption of the γ rays. In the experiment, no such inhibition of the absorption was found. This negative result set an upper limit of about 5 cm/s

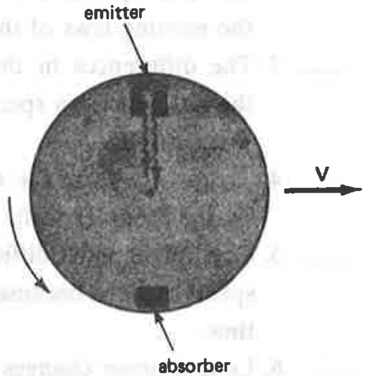


Figure 9-1. Source and Absorber of γ Rays on a Rotating Turntable.

on the ether wind. The experimental evidence therefore establishes beyond all reasonable doubt that the motion of the Earth has no effect whatsoever on the propagation of light.

Ohanian, H. C. (1986: pp. 70-73).

Part I. Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The main reason for Einstein's revolutionary proposal was his belief in the general validity of Maxwell's equations.

.... 2. The Principle of Relativity as suggested by Einstein did not affect the existing laws of the propagation of light.

.... 3. The differences in the frequencies of standing waves result from the differences in speeds, provided that resonant cavities are of the same length.

.... 4. The velocities of the receiver relative to the ether have no bearing on the Doppler shift.

.... 5. One might have difficulty in understanding the invariance of the speed of light because of general misconceptions about space and time.

.... 6. Length never changes in the course of time.

.... 7. Further experiments are needed to set upper limits of more than 5 cm/s in order to claim that the motion of the Earth has no bearing on the propagation of light.

.... 8. In modern versions of the Michelson-Morely experiments, lasers have been used only as resonant cavities.

.... 9. The rotation will change the value of the Doppler shift.

B. Choose a, b, c, or d which best completes each item.

1. The change of the reference frame of time ....

a. violates our common notions of length and space

b. has no bearing on our sense of vision

c. results in contraction of the length of the object studied

d. will not affect the speed of light

2. It was believed that ....

a. the Michelson-Morley experiment had left no room for improvement

b. the dependence of the theory of relativity on the invariance of light can be detected by intuition

c. the slightest motion of the Earth will affect the propagation of light

d. the experiments using precise interferometer should be performed to verify the Theory of Relativity

3. There is an indirect relationship between ....

a. the frequency of a standing wave and the speed of the wave

b. the two identical cavities and the difference in frequencies

c. the length of the cavity and the frequency of a standing wave

d. the lasers used as resonant cavities and the ether wind

4. Modern experiments using more precise devices have ....

a. shown that the Doppler shift cannot be used to detect the ether wind

b. proved without any doubt that the Doppler shift has a constant value

c. relied heavily on the Mössbauer effect in which the iron crystal absorbs light

d. proved that the propagation of light is not affected by the motion of the Earth

5. Einstein's radical proposal of the early 20th century was meant ....

a. to put an end to the Newtonian concepts of time and space

b. to overcome the contradiction of the invariance of the speed of light to the Galilean addition law

c. to resolve the negative results of the Michelson-Morley experiment

d. to summarize all the laws of physics in the form of a simple, compact and comprehensive general hypothesis

6. It is understood from the passage that ....

a. the revolutionary proposal of Einstein falsified all of the previous scientific works

b. it is impossible to put together all the laws of physics in a general principle

c. there was no relationship between the Galilean addition law and Newtonian concepts of space and time

d. even the most radical proposal in science draws heavily on the previous scientific works

C. Answer the following questions orally.

1. What is the Principle of Relativity?
2. What does Mössbauer effect mean?
3. What is so strange about the behavior of length and time?
4. What is the main difference between the modern and old versions of the Michelson-Morley experiment?

5. Which experiment has set the highest upper limit for the value of the ether wind?
6. How does the Principle of Relativity affect the propagation of light?
7. How does the change in the reference frame affect length and time?
8. Why is there a mismatch between the emitter and the absorber?
9. Why have many experimenters tried to improve the results of Michelson-Morley experiment?

Part II. Language Practice

A. Choose a, b, c, or d which best completes each item.

1. The apparent change in the frequency of sound or electromagnetic radiation due to relative motion between .... and the observer is referred to as Doppler principle.

a. the cause — c. the source
b. the beginning — d. the derivation

2. According to one of .... of the Theory of Special Relativity, the velocity of light is the same for all observers irrespective of their own velocity.

a. the teachings — c. the axioms
b. the principles — d. the maxims

3. The special significance of the velocity of light is apparent from its .... in the mass-energy equation.

a. residence — c. occupation
b. presence — d. attendance

4. The general Theory of Relativity applied to observers not in uniform relative motion .... to a novel concept of the theory of gravitation.

a. conducts — c. passes
b. guides — d. leads

5. The Mössbauer effect has been used to test .... of the Theory of Relativity.

a. the proclamations — c. the predictions
b. the generalizations — d. the suppositions

6. According to the Theory of Relativity the impossibility of determining .... motion leads to the concept of spare-time continuum.

a. full — c. sheer
b. absolute — d. total

B. Fill in the blanks with the appropriate form of the words given.

1. Propose

a. Various .... have been made for bringing the war to an end, but so far none of them has met with any response.

b. I will do cooperate in any plan .... by you if it is a practical one.

c. She put forward a .... so clear that it needs no explanation.

2. Identify

a. The Chinese twins were dressed ....

b. It took the engineers six months to .... the source of the trouble.

c. A machine will produce a thousand .... chairs, but in chairs made by hand there are always individual differences.

d. The police is still trying to find out the .... of the persons killed in the road accident.

3. Behave

a. Scientists have made a close study of the .... of monkeys living together in groups in the forest.

b. It is not always possible to predict how a particular person will .... in a new situation.

4. Contradict

a. A consistent argument is an argument which does not contain any ....

b. The president of the company has .... the report that the company will be sold next year.

c. His speech contained many .... statements.

5. Imply

a. His voice had an .... threat in it.

b. She was so kind that she refused the marriage proposal ....

c. To understand the .... of a situation, we have to know something about that kind of situation.

d. We understand what words and sentences .... through our knowledge of grammar and the language code and the typical (or sometimes special) contexts in which the words and sentences are used.

6. Employ

a. A lot of money can be saved by the .... of these techniques.

b. He has a degree in psychology, and is .... as a student advisor.

c. These machines are not ...., because they poison the atmosphere of our planet.

C. Fill in the blanks with the following words.

fundamental	principle	derived
equivalence	existence	motion
mechanics	familiar	finds

The crucial contribution to the development of the special relativity theory came from Einstein in his famous paper 'Zur Elektrodynamik bewegter Körper' (Electrodynamics of moving bodies), Am. Physik 17, 891-921 (1905). As we know today, one may assume that Einstein was not .... with Lorentz's 1904 work nor with Poincare's 1905 paper. Einstein .... that it is not necessary to assume the .... of an ether at rest. His starting point is that all experiments aimed at observing a/an .... relative to the ether failed. This then justifies one to demand that the .... of reference frames in uniform motion (a valid statement in Newtonian ....) should have *general* validity. (This statement is the 'Einstein Principle of Relativity'.) We must emphasize that in Einstein's work the Principle of Relativity has a/an .... axiomatic role in the theory. Consequence ....from it should be confronted with experiments.

D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. What, then, did Einstein do to make his name almost synonymous with relativity?

b. This is a well-deserved tribute to the enormous intellectual impact–still effective, more than 60 years after the event–of what Einstein called his *special theory* of relativity.

c. What is it that you first think of when you see or hear the word *relativity*?

d. The answer is that he led us to apply the notions of relativity to *all* our physical experience and not merely to a restricted range of phenomena.

e. It is, crudely speaking, just the assertion that the laws of physics appear the same in many different reference frames.

f. Very likely there will come to your mind the name of Albert Einstein, or the equation $E=mc^2$, or a vision of space travelers returning youthful from trips of many years' duration.

g. And the development of this theory by Einstein and others in the years around 1900 is rightly regarded as one of the greatest strides ever made in our way of describing and interpreting the physical world.

h. Yet the basic concept of relativity is as old as the mechanics of Galileo and Newton.

1	2	3	4	5	6	7	8

Section Two: Further Reading

Relativity in Perspective

The special theory of relativity has had, and still has, its share of fierce critics and detractors. However, it is supported by such a vast amount of experimental evidence that it is very difficult seriously to doubt it. The body of evidence is so wide-ranging that it resembles the evidence which had been amassed in support of classical dynamics by the beginning of this century. Therefore if any theory should ever be devised which supersedes special relativity, it must surely be set up in such a way that special relativity will remain as a special case of the new theory. To put it another way, any new theory must be asymptotic to special relativity just as special relativity is asymptotic to classical relativity and classical dynamics. The principles and details of special relativity are probably best regarded not as absolutely true but as the best and most concise way yet devised for describing a vast amount of experimental data.

The general theory of relativity, on the other hand, is much less secure. There are only a few experimental tests of the theory and these all involve measurements of extreme difficulty which are at or near limits of the accuracy at present attainable. The best experimental test, the discrepancy in the orbit or Mercury, is not totally convincing, since the observed discrepancy is in fact a residual discrepancy after several substantial corrections have been made to the initial observations. The effect actually observed is more than a hundred times greater than the discrepancy for which general relativity accounts. Also it has recently been suggested that the discrepancy could be explained if the sun should turn out to be not quite spherical in shape. The degree of flattening required to make a substantial contribution to the discrepancy is only about one part in ten thousand and careful experiments are now going on to see if such a flattening can be directly measured by optical observation of the sun.

These doubts, however, are mainly centred on the detailed working out of the theory of general relativity. They do not mean that the basic principle, the principle of the equivalence of gravitation and inertia, is necessarily suspect. And in fact the evidence for this principle is generally considered to be extremely strong. A recent development in this field has been the working out of a whole series of theories based on the same basic principles as general relativity but differing in the detailed mathematical way in which the principles are incorporated into the theories. From the point of view of this work, Einstein's general relativity is seen as just one theory out of a whole class of theories all stemming from the principles of equivalence. General relativity is the simplest of these theories, but of course simplicity alone is no argument in its favour.

Another development, first started by Einstein and since carried on by a large number of other theoretical physicists, has been an attempt to incorporate electromagnetic and nuclear forces into a unified theory in a way similar to that in which gravitation was incorporated into general relativity. Despite much effort, however, this work does not seem to have reached a satisfactory conclusion.

Another aspect of gravitation, which has also been the subject of much study, is the possibility of observing gravitational waves produced by the rapid movement of massive objects in much the same way as electromagnetic waves are produced by the rapid movement of electric charges. The theory of gravitational waves is so much more complicated than that of electromagnetic waves and any possible experiments to detect them are so difficult that progress has been slow. Recently, however, in experiments involving the use of sensitive seismometers, there have been reports of the detection of some very small effects which may be attributable to gravitational waves reaching the earth from somewhere in the universe.

Finally let us briefly mention a topic which is basic to the whole subject of dynamics and that is to ask what is the source of the inertia of matter, or, alternatively, why it is that inertial motion is distinguished from all other types of motion and inertial observers are in a class by themselves. This subject was considered as long ago as 1880 by Mach in a book on the history of dynamics in which he suggested that the inertial properties of any particular piece of matter were in some way attributable to the influence of all the other matter in the universe. Unfortunately he did not give any detailed theory of this influence but the basic idea, or Mach's principle as it is called, has intrigued many people ever since. The principle seems to imply that if, in some way, say half the matter in the universe were to be removed, then the inertial properties of the remaining matter would be altered and gravitational forces would be considerably reduced. Unfortunately for a scientific test of Mach's principle, this sort of experiment is difficult to perform! However, efforts are being made to try and work out a detailed theory of the interaction involved so that some more easily testable predictions can be made.

The resolution of all these tentative ideas and suggestions most probably depends on a combination of three things, the improvement of experimental techniques in terrestrial measurements, the discovery of suitable events to study in that natural laboratory, the universe, and finally the further development of the science of cosmology, the science which studies the nature, origin and history of the universe as a whole. All these things are difficult and so progress is likely to be slow. It is also likely, if past experience is any guide, that the resolution of one problem or difficulty will bring into view another more subtle and elusive problem for the next generation of scientists to tackle.

We might absorb two things from this account of the theories of relativity–first, that traditional ideas are not necessarily the whole truth about anything, no matter for how long they have been held or how many people may subscribe to them, and secondly, that the beauty, simplicity or intuitive appeal of any concept is no sure guide to its validity, since the world or the universe may well be ugly, complicated and inaccessible to our intuition.

Marks, J. (1972: pp. 115-118).

Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. The special theory of relativity has been accepted full heartedly by all scientists.

.... 2. Theoretical physicists have succeeded in bringing together electromagnetic and nuclear forces into a comprehensive theory.

.... 3. There are different kinds of motions of which inertial is just one.

.... 4. A verbal explanation of any theory without a detailed mathematical exposition of it will be incomplete.

.... 5. Traditional ideas which are subscribed to by many people for a long period of time usually contain the whole truth.

.... 6. The number of the supporters of the special theory of relativity is much more than its critics.

.... 7. The principles and details of special relativity are absolutely true.

.... 8. The best experimental test of the theory of the general relativity is that of Mach.

.... 9. The basic test of the theory of general relativity is referred to as the discrepancy in the orbit of Mercury.

B. Choose a, b, c, or d which best completes each item.

1. The special theory of relativity is so accurate that ....

a. it cannot be supplemented by any new theory
b. its principles will always be valid
c. it cannot be contradicted completely
d. its details do not need further experimental evidence

2. The assumption that the sun is not quite spherical has ....

a. a bearing on the validity of the general theory of relativity
b. not been experimentally proven to be quite true
c. to be forgotten in favour of a somewhat flat sun
d. not contributed substantially to the discrepancy in the orbit of Mercury

3. General relativity is one of the theories which ....

a. makes use of classical dynamics
b. is considered to be extremely strong
c. has been verified to be completely correct
d. is based on the principle of equivalence

4. It is hoped that future research will ....

a. clarify the effects of electromagnetic forces on massive objects
b. enable physicists to observe the electromagnetic waves
c. clarify the theory of gravitational waves
d. enable physicists to detect the source of the gravitational waves

5. Once extreme difficulties of measurement are overcome, ...

a. the next generation of physicists will have nothing to tackle
b. some of the problems will still remain unresolved
c. the relation between relativity and philosophy will become clear
d. general relativity will not be regarded as the simplest of the related theories

6. Taking into consideration all the detailed calculations and precise experiments, it can be said that ....

a. there is nothing inaccessible to our intuition in the universe

b. Mach's principle will be experimentally tested in near future
c. classical dynamics has no role to play in modern physics
d. the theory of special relativity is more valid than general relativity

C. Write the answers to the following questions.

1. What is the difference between a complete set of new theories which are based on the same principle as general relativity?
2. What difference will the probable flattening of the sun make in the general theory of relativity?
3. What is the similarity between gravitational and electromagnetic waves?
4. What is the difference between general relativity and other theories based on the same principle?
5. What makes the study of the gravitational waves difficult?
6. What is the relationship of seismometers to the experimental test of general relativity?
7. What role can the further development of cosmology play in solving the problems based on general relativity?
8. What is the basic principle of the theory of general relativity?
9. Why is the simplicity of general relativity not enough to account for problems tackled by physicists?

Section Three: Translation Activities

A. Translate the following passage into Persian.

The Relativistic Domain

The basic concepts of relativity occur in two forms: the **special theory of relativity** and the **general theory of relativity**. The special theory is used to treat the rapid motion of objects, of any size, as seen from inertial reference frames. It is the original form of the theory, developed by Einstein in 1905, and by far the simplest. The general theory has to do with noninertial (that is, accelerating) reference frames and their relation to gravity. This form of the theory, first set forth by Einstein in 1916, is used for the most part to treat the behavior of very massive systems. These are generally ones at the large end of the natural scale of sizes, that is, systems of astronomical size. Because of its mathematical complexity, we only mention the existence of the general theory.

The mechanics we will develop to analyze motion on the basis of the special theory of relativity is known as relativistic mechanics. It is used to study the high-speed motion of objects over the entire range of sizes. Relativistic mechanics applies over the entire range of speeds, its results merging smoothly into those of Newtonian mechanics when the speed is low compared to the speed of light. It is the more broadly applicable mechanics, valid from zero speed to the speed of light. (We will find that the range of possible speeds for any object ends at the speed of light: higher speeds cannot be attained.) To put the matter another way, the rules of Newtonian mechanics emerge as the low-speed special case of the more broadly applicable relativistic mechanics.

B. Find the Persian equivalents of the following terms and expressions and write them in the spaces provided.

1. cosmology ....
2. dilation ....
3. Doppler shift ....
4. emitter ....
5. ether wind ....
6. general relativity ....
7. gravitational wave ....
8. inertial motion ....
9. inertial reference frames ....
10. interferometer ....
11. invariance ....
12. Mach's principle ....
13. mass-energy equation ....
14. Mössbauer effect ....
15. receiver ....
16. recoil momentum ....
17. recoilless transition ....
18. reference frame ....
19. relativistic mass ....
20. residual discrepancy ....
21. resonant cavity ....
22. special relativity ....
23. standing waves ....
24. terrestrial measurement ....
25. transformation equation ....

Unit **10**

Section One: Reading Comprehension

Nuclear Physics

Chain Reactions

Although spontaneous fission in ^{238}U is rare, this nucleus is susceptible to induced fission when subjected to bombardment by neutrons. The collision of a neutron with a nucleus and its absorption initiates violent vibrations of the nucleus, which are likely to split it apart. This results in **neutron-induced fission reaction,** such as

$$n+{}^{238}U \rightarrow {}^{145}Ba+{}^{94}Kr \qquad (10\text{-}1)$$

Incidentally: the reaction (10-1) is of some historical interest, since it led to the discovery of fission in 1938 by O. Hahn and F. Strassmann, who detected barium in a sample of uranium irradiated by neutrons.

Both of the fission fragments released in the reaction (10-1) are very neutron rich, and they almost immediately eject two or three of their excess neutrons. The net reaction in neutron-induced fission of ^{238}U can therefore be summarized as

$$n+{}^{238}U \rightarrow \text{fission fragments}+2n \text{ or } 3n \qquad (10\text{-}2)$$

Practical applications of fission rely on the neutrons released in this reaction to induce further fission reactions. If we trigger a first fission in a sample of uranium, the neutrons released in this first fission there will collide with other uranium nuclei and induce their fission, and the neutrons released there will induce further fissions, etc. (see Figure 10-1). The result is a self-sustaining **chain reaction.** Provided no neutrons, or only few neutrons, are lost from this chain, the result is an avalanche of neutrons and of fissions. In such an avalanche the number of neutrons and the number of fissions in successive steps of the chain grow geometrically. For example, if on the average two neutrons are released per fission reaction and each of these neutrons induces a further fission reaction, then the number of fissions in successive steps of the chain will be 2, 4, 8, 16, 64, ... This geometric growth of the reaction rate leads to an explosive release of energy.

The cross section for neutron-induced fission reactions depends on the neutron energy. In the case of ^{238}U, the minimum neutron energy required for initiating the fission reaction is 1.2 MeV. Neutrons of this energy or a larger

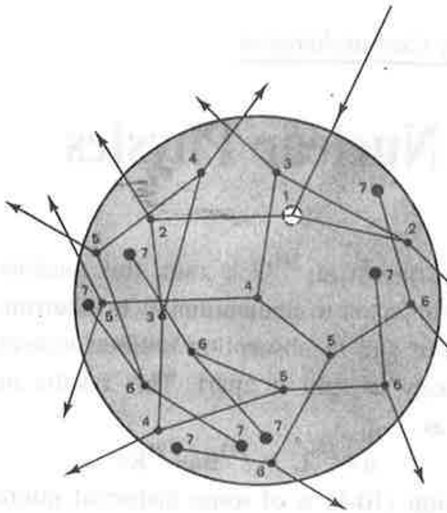


Figure 10-1. Chain Reaction Initiated by a Single Fission at the Point 1.

energy are called **fast neutrons**. The neutrons released in fission of ^{238}U are initially fast but they are likely to suffer several consecutive inelastic collisions with nuclei before they are finally absorbed in one of these collisions. In such inelastic collisions, the neutrons lose most of their kinetic energy, and when they are finally absorbed, their residual energy is insufficient to trigger a fission. Thus, the inelastic collisions effectively remove neutrons from the fission chain, and thereby inhibit the chain reaction. The most likely final fate of a low-energy neutron is absorption by a uranium nucleus according to the reaction

$$n + {}^{238}U \rightarrow {}^{239}U \qquad (10\text{-}3)$$

Hence ^{238}U tends to soak up neutrons without undergoing fission, and it will not sustain a chain reaction.

In the case of ^{235}U, there is no minimum neutron energy required for fission. This nucleus is rather unstable, and it will fission even if the energy of the incident neutron is very low, because the binding energy that becomes available when the neutron is captured by the nucleus is by itself sufficient to initiate the fission reaction. In fact, the cross section for induced fission is largest for incident neutrons of the lowest energy (1 *r* law), because the slowest neutrons spend the longest time passing through the nucleus, which enhances the probability that an absorption reaction will occur. Thus, ^{235}U will sustain a chain reaction–it is a **fissile** material.

The abundance of ^{235}U in naturally occurring uranium ores is quite low–such ores consists of about 99.3% ^{238}U and only 0.7% ^{235}U. Since the mass difference between these isotopes is small, their separation is difficult. It can be accomplished by converting them into uranium hexafluoride, a gaseous compound, in which the two isotopes can be segregated by diffusion through membranes or by centrifugation.

Besides ^{235}U, there exist two other isotopes suitable for chain reactions. Both resemble ^{235}U in that the spontaneous decay rate is low (so they can be held in storage without serious loss) and in that the fissions can be induced by neutrons of low energy: one is ^{233}U and the other is an isotope of plutonium, ^{239}Pu. The latter is very fissile, but it is not found in ores on the Earth; it can only be obtained by artificial means, by nuclear transmutation.

The geometric growth of the reaction rate in a chain reaction is described mathematically by the **multiplication factor**, i.e., the factor by which the number of neutrons increases in successive steps along the fission chain. If no neutrons are lost from the fission chain, then the multiplication factor is simply equal to the average number of neutrons released per fission; but if some neutrons are lost, then the multiplication factor will be smaller. The mass of fissile material is said to be in a **critical** condition if the multiplication factor is unity; the chain reaction then merely proceeds at a constant rate–as in a nuclear reactor. The mass is in a **supercritical** condition if the multiplication factor exceeds unity; the chain reaction then proceeds at a geometrically increasing rate, leading to an explosion–as in a nuclear bomb.

Ohanian, H. C. (1987: pp. 422-424).

Part I. Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

.... 1. Only the loss of significant number of neutrons will affect the chain reaction.

.... 2. Centrifugation may be used to separate the isotopes of some kinds of uranium.

.... 3. A fissile material usually soakes up neutrons without undergoing further fission.

.... 4. Naturally occurring uranium ores contain plenty of ^{235}U.

.... 5. There are two methods of separating ^{238}U from ^{235}U isotopes.

.... 6. There is a direct relationship between the loss of neutrons in the fission chain and the amount of multiplication factor.