Chapter Fifteen

COMMUNICATION SYSTEMS

15.1 Introduction

Communication is the act of transmission of information. Every living creature in the world experiences the need to impart or receive information almost continuously with others in the surrounding world. For communication to be successful, it is essential that the sender and the receiver understand a common *language*. Man has constantly made endeavors to improve the quality of communication with other human beings. Languages and methods used in communication have kept evolving from prehistoric to modern times, to meet the growing demands in terms of speed and complexity of information. It would be worthwhile to look at the major milestones in events that promoted developments in communications, as presented in Table 15.1.

Modern communication has its roots in the 19^{th} and 20^{th} century in the work of scientists like J.C. Bose, F.B. Morse, G. Marconi and Alexander Graham Bell. The pace of development seems to have increased dramatically after the first half of the 20^{th} century. We can hope to see many more accomplishments in the coming decades. The aim of this chapter is to introduce the concepts of communication, namely the mode of communication, the need for modulation, production and deduction of amplitude modulation.

15.2 Elements of a Communication System

Communication pervades all stages of life of all living creatures. Irrespective of its nature, every communication system has three essential elements-

TABLE 15.1 SOME MAJOR MILESTONES IN THE HISTORY OF COMMUNICATION

Year	Event	Remarks
Around 1565 A.D.	The reporting of the delivery of a child by queen using drum beats from a distant place to King Akbar.	It is believed that minister Birbal experimented with the arrangement to decide the number of drummers posted between the place where the queen stayed and the place where the king stayed.
1835	Invention of telegraph by Samuel F.B. Morse and Sir Charles Wheatstone	It resulted in tremendous growth of messages through post offices and reduced physical travel of messengers considerably.
1876	Telephone invented by Alexander Graham Bell and Antonio Meucci	Perhaps the most widely used means of communication in the history of mankind.
1895	Jagadis Chandra Bose and Guglielmo Marconi demonstrated wireless telegraphy.	It meant a giant leap communication using wires to communicating without using wires. (wireless)
1936	Television broadcast(John Logi Baird)	First television broadcast by BBC
1955	First radio FAX transmitted across continent.(Alexander Bain)	The idea of FAX transmission was patented by Alexander Bain in 1843.
1968	ARPANET- the first internet came into existence(J.C.R. Licklider)	ARPANET was a project undertaken by the U.S. defence department. It allowed file transfer from one computer to another connected to the network.
1975	Fiber optics developed at Bell Laboratories	Fiber optical systems are superior and more economical compared to traditional communication systems.
1989-91	Tim Berners-Lee invented the World Wide Web.	WWW may be regarded as the mammoth encyclopedia of knowledge accessible to everyone round the clock throughout the year.

transmitter, medium/channel and receiver. The block diagram shown in Fig. 15.1 depicts the general form of a communication system.

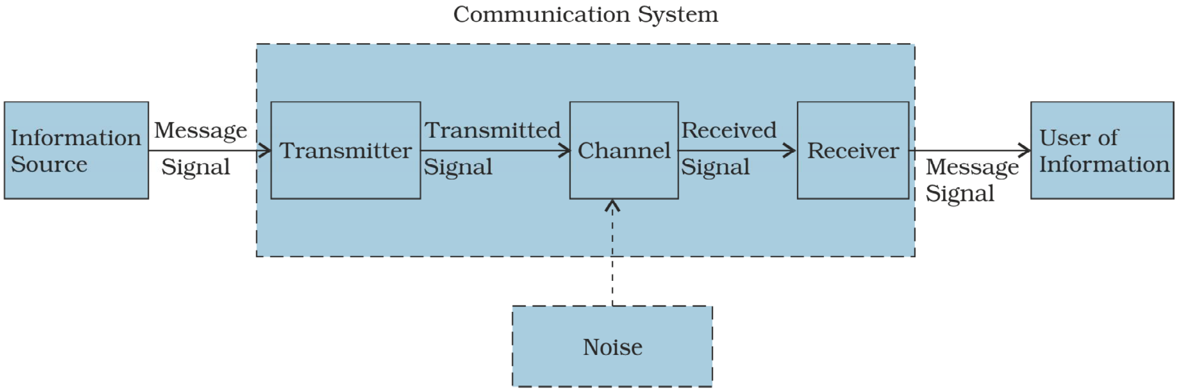

FIGURE 15.1 Block diagram of a generalised communication system.

In a communication system, the transmitter is located at one place, the receiver is located at some other place (far or near) separate from the transmitter and the channel is the physical medium that connects them. Depending upon the type of communication system, a channel may be in the form of wires or cables connecting the transmitter and the receiver or it may be wireless. The purpose of the transmitter is to convert the message signal produced by the source of information into a form suitable for transmission through the channel. If the output of the information source is a non-electrical signal like a voice signal, a transducer converts it to electrical form before giving it as an input to the transmitter. When a transmitted signal propagates along the channel it may get distorted due to channel imperfection. Moreover, noise adds to the transmitted signal and the receiver receives a corrupted version of the transmitted signal. The receiver has the task of operating on the received signal. It reconstructs a recognisable form of the original message signal for delivering it to the user of information.

There are two basic modes of communication: *point-to-point* and *broadcast*.

In point-to-point communication mode, communication takes place over a link between a single transmitter and a receiver. Telephony is an example of such a mode of communication. In contrast, in the broadcast mode, there are a large number of receivers corresponding to a single transmitter. Radio and television are examples of broadcast mode of communication.

15.3 Basic Terminology Used in Electronic Communication Systems

By now, we have become familiar with some terms like information source, transmitter, receiver, channel, noise, etc. It would be easy to understand the principles underlying any communication, if we get ourselves acquainted with the following basic terminology.

JAGADIS CHANDRA BOSE (1858

Jagadis Chandra Bose (1858 He developed an apparatus for generating ultrashort electro-magnetic waves and studied their quasi-optical properties. He was said to be the first to employ a semiconductor like galena as a self-recovering detector of electromagnetic waves. Bose published three papers in the British magazine, Electrician 1895. His invention was published in the

Society over two years before Marconi communication on 13 December 1901. Bose also invented highly sensitive instruments for the detection of minute responses by living organisms to external stimulii and established parallelism between animal and plant tissues.

(i) *Transducer:* Any device that converts one form of energy into another can be termed as a transducer. In electronic communication systems, we usually come across devices that have either their inputs or outputs in the electrical form. An electrical transducer may be defined as a device that converts some physical variable (pressure, displacement, force, temperature, etc) into corresponding variations in the electrical signal at its output.

(ii) *Signal:* Information converted in electrical form and suitable for transmission is called a signal. Signals can be either *analog or digital*. Analog signals are continuous variations of voltage or current. *They are essentially single-valued functions of time*. Sine wave is a fundamental analog signal. All other analog signals can be fully understood in terms of their sine wave components. Sound and picture signals in TV are analog in nature. Digital signals are those which can take only discrete stepwise values. Binary system that is extensively used in digital electronics employs just two levels of a signal.
level and
current. There are several coding schemes useful for digital communication. They employ suitable combinations of number systems such as the binary coded decimal (BCD)*. American Standard Code for Information Interchange (ASCII)** is a universally popular digital code to represent numbers, letters and certain characters.

(iii) *Noise:* Noise refers to the unwanted signals that tend to disturb the transmission and processing of message signals in a communication system. The source generating the noise may be located inside or outside the system.

(iv) *Transmitter:* A transmitter processes the incoming message signal so as to make it suitable for transmission through a channel and subsequent reception.

(v) *Receiver:* A receiver extracts the desired message signals from the received signals at the channel output.

(vi) *Attenuation:* The loss of strength of a signal while propagating through a medium is known as attenuation.

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* In BCD, a digit is usually represented by four binary (0 or 1) bits. For example the numbers 0, 1, 2, 3, 4 in the decimal system are written as 0000, 0001, 0010, 0011 and 0100. 1000 would represent eight.

** It is a character encoding in terms of numbers based on English alphabet since the computer can only understand numbers.

(vii) *Amplification:* It is the process of *increasing the amplitude* (and consequently the strength) of a signal using an electronic circuit called the amplifier (reference Chapter 14). Amplification is necessary to compensate for the attenuation of the signal in communication systems. The energy needed for additional signal strength is obtained from a DC power source. Amplification is done at a place between the source and the destination wherever signal strength becomes weaker than the required strength.

(viii) *Range:* It is the largest distance between a source and a destination up to which the signal is received with sufficient strength.

(ix) *Bandwidth:* Bandwidth refers to the frequency range over which an equipment operates or the portion of the spectrum occupied by the signal.

(x) *Modulation:* The original low frequency message/information signal cannot be transmitted to long distances because of reasons given in Section 15.7. Therefore, at the transmitter, information contained in the low frequency message signal is superimposed on a high frequency wave, which acts as a carrier of the information. This process is known as modulation. As will be explained later, there are several types of modulation, abbreviated as AM, FM and PM.

(xi) *Demodulation:* The process of retrieval of information from the carrier wave at the receiver is termed demodulation. This is the reverse process of modulation.

(xii) *Repeater:* A repeater is a combination of a receiver and a transmitter. A repeater, picks up the signal from the transmitter, amplifies and retransmits it to the receiver sometimes with a change in carrier frequency. Repeaters are used to extend the range of a communication system as shown in Fig. 15.2. A communication satellite is essentially a repeater station in space.

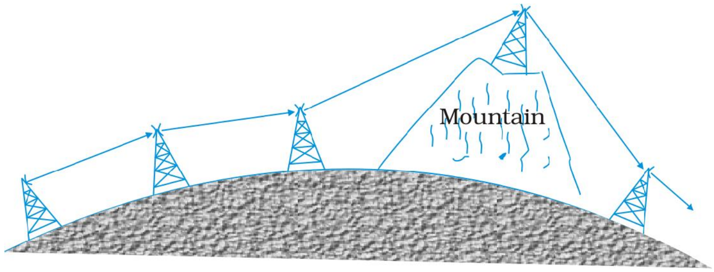

FIGURE 15.2 Use of repeater station to increase the range of communication.

15.4 Bandwidth of Signals

In a communication system, the message signal can be voice, music, picture or computer data. Each of these signals has different ranges of frequencies. The type of communication system needed for a given signal depends on the band of frequencies which is considered essential for the communication process.

For speech signals, frequency range 300 Hz to 3100 Hz is considered adequate. Therefore speech signal requires a bandwidth of 2800 Hz (3100 Hz an approximate bandwidth of 20 kHz is required because of the high frequencies produced by the musical instruments. The audible range of frequencies extends from 20 Hz to 20 kHz.

Video signals for transmission of pictures require about 4.2 MHz of bandwidth. A TV signal contains both voice and picture and is usually allocated 6 MHz of bandwidth for transmission.

In the preceeding paragraph, we have considered only analog signals. Digital signals are in the form of rectangular waves as shown in Fig. 15.3. One can show that this rectangular wave can be decomposed into a superposition of sinusoidal waves of frequencies ν_0, $2\nu_0$, $3\nu_0$, $4\nu_0$ ... $n\nu_0$ where n is an integer extending to infinity and $\nu_0 = 1/T_0$. The fundamental (ν_0), fundamental (ν_0) + second harmonic ($2\nu_0$), and fundamental (ν_0) + second harmonic ($2\nu_0$) + third harmonic ($3\nu_0$), are shown in the same figure to illustrate this fact. It is clear that to reproduce the rectangular wave shape exactly we need to superimpose all the harmonics ν_0, $2\nu_0$, $3\nu_0$, $4\nu_0$..., which implies an infinite bandwidth. However, for practical purposes, the contribution from higher harmonics can be neglected, thus limiting the bandwidth. As a result, received waves are a distorted version of the transmitted one. If the bandwidth is large enough to accommodate a few harmonics, the information is not lost and the rectangular signal is more or less recovered. This is so because the higher the harmonic, less is its contribution to the wave form.

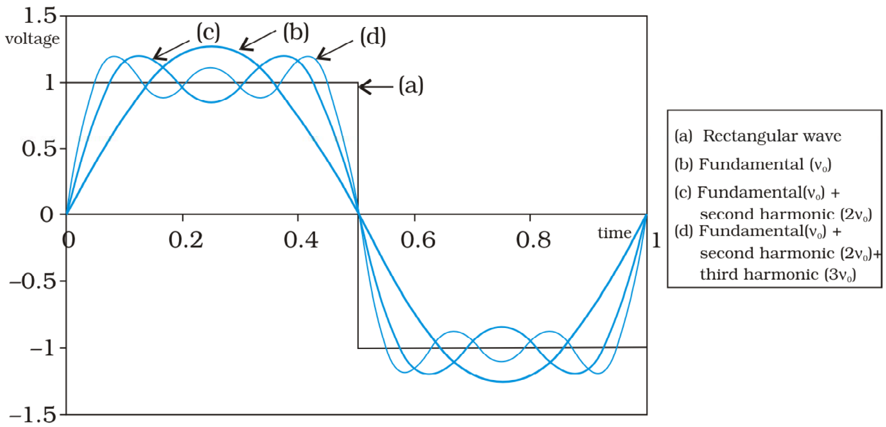

FIGURE 15.3 Approximation of a rectangular wave in terms of a fundamental sine wave and its harmonics.

15.5 BANDWIDTH OF TRANSMISSION MEDIUM

Similar to message signals, different types of transmission media offer different bandwidths. The commonly used transmission media are wire, free space and fiber optic cable. Coaxial cable is a widely used wire medium, which offers a bandwidth of approximately 750 MHz. Such cables are normally operated below 18 GHz. Communication through free space using radio waves takes place over a very wide range of frequencies: from a few hundreds of kHz to a few GHz. This range of frequencies is further subdivided and allocated for various services as indicated in Table 15.2. Optical communication using fibers is performed in the frequency range of 1 THz to 1000 THz (microwaves to ultraviolet). An optical fiber can offer a transmission bandwidth in excess of 100 GHz.

Spectrum allocations are arrived at by an international agreement. The International Telecommunication Union (ITU) administers the present system of frequency allocations.

TABLE 15.2 SOME IMPORTANT WIRELESS COMMUNICATION FREQUENCY BANDS

Service	Frequency bands	Comments
Standard AM broadcast	540-1600 kHz	
FM broadcast	88-108 MHz	
Television	54-72 MHz	VHF (very high frequencies)
	76-88 MHz	TV
	174-216 MHz	UHF (ultra high frequencies)
	420-890 MHz	TV
Cellular Mobile Radio	896-901 MHz	Mobile to base station
	840-935 MHz	Base station to mobile
Satellite Communication	5.925-6.425 GHz	Uplink
	3.7-4.2 GHz	Downlink

15.6 PROPAGATION OF ELECTROMAGNETIC WAVES

In communication using radio waves, an antenna at the transmitter radiates the Electromagnetic waves (em waves), which travel through the space and reach the receiving antenna at the other end. As the em wave travels away from the transmitter, the strength of the wave keeps on decreasing. Several factors influence the propagation of em waves and the path they follow. At this point, it is also important to understand the composition of the earth
propagation of em waves. A brief discussion on some useful layers of the atmosphere is given in Table 15.3.

15.6.1 Ground wave

To radiate signals with high efficiency, the antennas should have a size comparable to the wavelength λ of the signal (at least ~ $\lambda/4$). At longer wavelengths (i.e., at lower frequencies), the antennas have large physical size and they are located on or very near to the ground. In standard AM broadcast, ground based vertical towers are generally used as transmitting antennas. For such antennas, ground has a strong influence on the propagation of the signal. The mode of propagation is called surface wave propagation and the wave glides over the surface of the earth. A wave induces current in the ground over which it passes and it is attenuated as a result of absorption of energy by the earth. The attenuation of surface waves increases very rapidly with increase in frequency. The maximum range of coverage depends on the transmitted power and frequency (less than a few MHz).

TABLE 15.3 DIFFERENT LAYERS OF ATMOSPHERE AND THEIR INTERACTION WITH THE PROPAGATING ELECTROMAGNETIC WAVES

Name of the stratum (layer)		Approximate height over earth	Exists during	Frequencies most affected
Troposphere		10 km	Day and night	VHF (up to several GHz)
D (part of stratosphere)	PARTS OF IONOSPHERE	65-75 km	Day only	Reflects LF, absorbs MF and HF to some degree
E (part of Stratosphere)		100 km	Day only	Helps surface waves, reflects HF
F_1 (Part of Mesosphere)		170-190 km	Daytime, merges with F_2 at night	Partially absorbs HF waves yet allowing them to reach F_2
F_2 (Thermosphere)		300 km at night, 250-400 km during daytime	Day and night	Efficiently reflects HF waves, particularly at night

15.6.2 Sky waves

In the frequency range from a few MHz up to 30 to 40 MHz, long distance communication can be achieved by ionospheric reflection of radio waves back towards the earth. This mode of propagation is called *sky wave propagation* and is used by short wave broadcast services. The ionosphere is so called because of the presence of a large number of ions or charged particles. It extends from a height of ~ 65 Km to about 400 Km above the earth

and other high-energy radiation coming from the sun by air molecules. The ionosphere is further subdivided into several layers, the details of which are given in Table 15.3. The degree of ionisation varies with the height. The density of atmosphere decreases with height. At great heights the solar radiation is intense but there are few molecules to be ionised. Close to the earth, even though the molecular concentration is very high, the radiation intensity is low so that the ionisation is again low. However, at some intermediate heights, there occurs a peak of ionisation density. The ionospheric layer acts as a reflector for a certain range of frequencies (3 to 30 MHz). Electromagnetic waves of frequencies higher than 30 MHz penetrate the ionosphere and escape. These phenomena are shown in the Fig. 15.4. The phenomenon of bending of em waves so that they are diverted towards the earth is similar to total internal reflection in optics*.

* Compare this with the phenomenon of mirage.

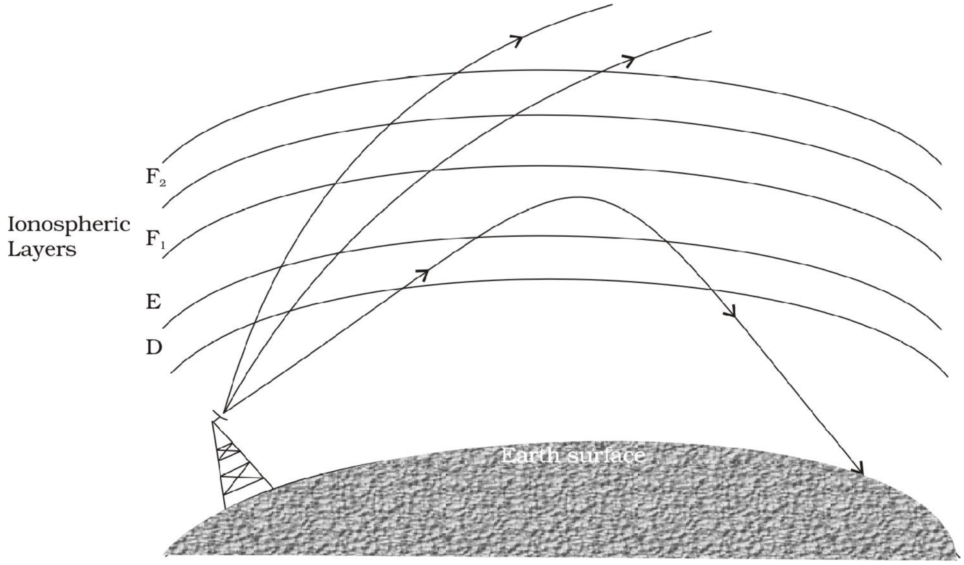

FIGURE 15.4 Sky wave propagation. The layer nomenclature is given in Table 15.3.

15.6.3 Space wave

Another mode of radio wave propagation is by *space waves*. A space wave travels in a straight line from transmitting antenna to the receiving antenna. Space waves are used for line-of-sight (LOS) communication as well as satellite communication. At frequencies above 40 MHz, communication is essentially limited to line-of-sight paths. At these frequencies, the antennas are relatively smaller and can be placed at heights of many wavelengths above the ground. Because of line-of-sight nature of propagation, direct waves get blocked at some point by the curvature of the earth as illustrated in Fig. 15.5. If the signal is to be received beyond the horizon then the receiving antenna must be high enough to intercept the line-of-sight waves.

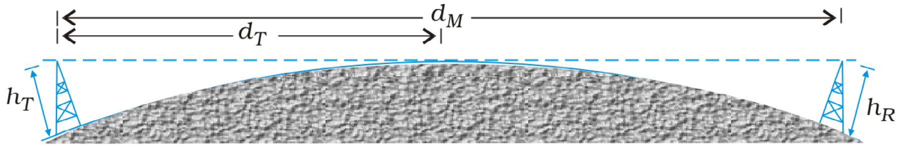

FIGURE 15.5 Line of sight communication by space waves.

If the transmitting antenna is at a height h_T, then you can show that the distance to the horizon d_T is given as $d_T = \sqrt{2Rh_T}$, where R is the radius of the earth (approximately 6400 km). d_T is also called the radio horizon of the transmitting antenna. With reference to Fig. 15.5 the maximum line-of-sight distance d_M between the two antennas having heights h_T and h_R above the earth is given by

$$d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R} \qquad (15.1)$$

where h_R is the height of receiving antenna.

Television broadcast, microwave links and satellite communication are some examples of communication systems that use space wave mode of propagation. Figure 15.6 summarises the various modes of wave propagation discussed so far.

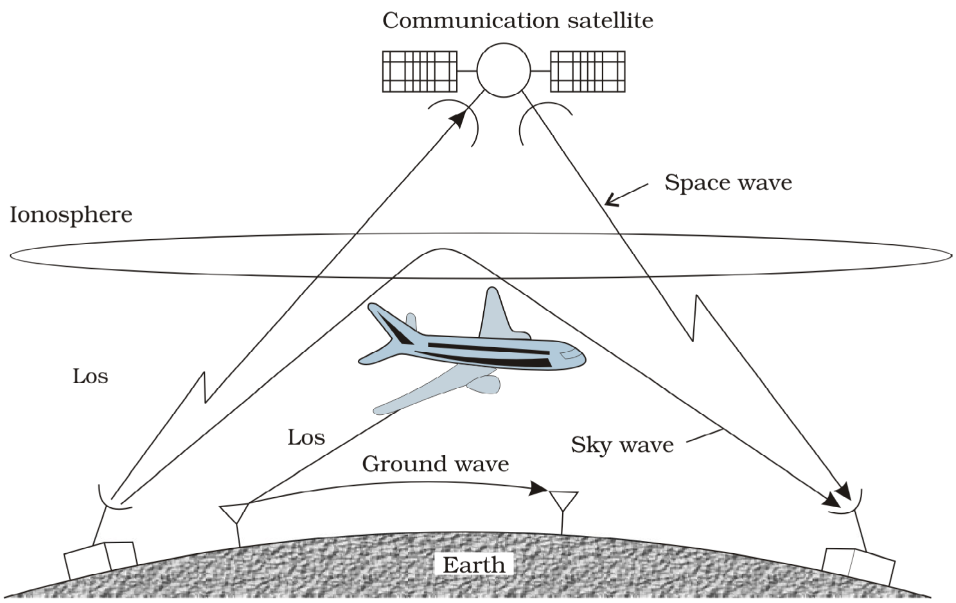

FIGURE 15.6 Various propagation modes for em waves.

EXAMPLE 15.1

Example 15.1 A transmitting antenna at the top of a tower has a height 32 m and the height of the receiving antenna is 50 m. What is the maximum distance between them for satisfactory communication in LOS mode? Given radius of earth 6.4×10^6 m.

Solution

$$d_m = \sqrt{2 \times 64 \times 10^5 \times 32} + \sqrt{2 \times 64 \times 10^5 \times 50} \text{ m}$$

$$= 64 \times 10^2 \times \sqrt{10} + 8 \times 10^3 \times \sqrt{10} \text{ m}$$

$$= 144 \times 10^2 \times \sqrt{10} \text{ m} = 45.5 \text{ km}$$

15.7 Modulation and its Necessity

As already mentioned, the purpose of a communication system is to transmit information or message signals. Message signals are also called *baseband signals*, which essentially designate the band of frequencies representing the original signal, as delivered by the source of information. No signal, in general, is a single frequency sinusoid, but it spreads over a range of frequencies called the signal *bandwidth*. Suppose we wish to transmit an electronic signal in the audio frequency (AF) range (baseband signal frequency less than 20 kHz) over a long distance directly. Let us find what factors prevent us from doing so and how we overcome these factors,

15.7.1 Size of the antenna or aerial

For transmitting a signal, we need an antenna or an aerial. This antenna should have a size comparable to the wavelength of the signal (at least $\lambda/4$ in dimension) so that the antenna properly senses the time variation of the signal. For an electromagnetic wave of frequency 20 kHz, the wavelength λ is 15 km. Obviously, such a long antenna is not possible to construct and operate. Hence direct transmission of such baseband signals is not practical. We can obtain transmission with reasonable antenna lengths if transmission frequency is high (for example, if ν is 1 MHz, then λ is 300 m). Therefore, there is a need of *translating the information contained in our original low frequency baseband signal into high or radio frequencies before transmission*.

15.7.2 Effective power radiated by an antenna

A theoretical study of radiation from a linear antenna (length l) shows that the power radiated is proportional to $(l/\lambda)^2$. This implies that for the same antenna length, the power radiated increases with decreasing λ, i.e., increasing frequency. Hence, the effective power radiated by a long wavelength baseband signal would be small. For a good transmission, we need high powers and hence this also points out to *the need* of using high frequency transmission.

15.7.3 Mixing up of signals from different transmitters

Another important argument against transmitting baseband signals directly is more *practical* in nature. Suppose many people are talking at the same time or many transmitters are transmitting baseband information signals simultaneously. All these signals will get mixed up and there is no simple way to distinguish between them. This points out towards a possible solution by using communication at high frequencies and allotting a *band* of frequencies to each message signal for its transmission.

The above arguments suggest that there is a *need for translating the original low frequency baseband message or information signal into high frequency wave before transmission such that the translated signal continues to possess the information contained in the original signal*. In doing so, we take the help of a high frequency signal, known as the *carrier wave*, and a process known as modulation which attaches information to it. The carrier wave may be continuous (sinusoidal) or in the form of pulses as shown in Fig. 15.7.

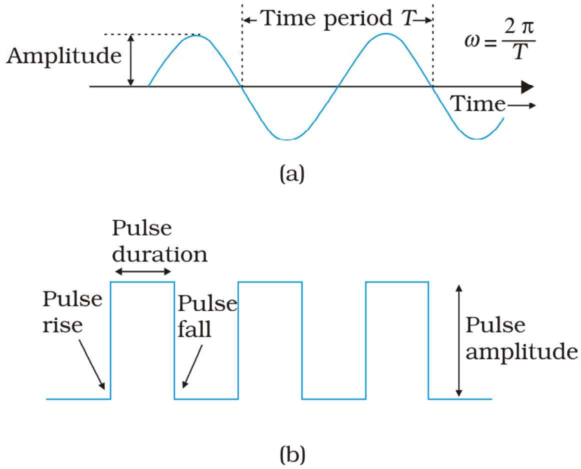

FIGURE 15.7 (a) Sinusoidal, and (b) pulse shaped signals.

A sinusoidal carrier wave can be represented as

$$c(t) = A_c \sin(\omega_c t + \phi) \qquad (15.2)$$

where $c(t)$ is the signal strength (voltage or current), A_c is the amplitude, ω_c ($= 2\pi\nu_c$) is the angular frequency and ϕ is the initial phase of the carrier wave. During the process of modulation, any of the three parameters, *viz* A_c, ω_c and ϕ, of the carrier wave can be controlled by the message or information signal. This results in three types of modulation: (i) Amplitude modulation (AM), (ii) Frequency modulation (FM) and (iii) Phase modulation (PM), as shown in Fig. 15.8.

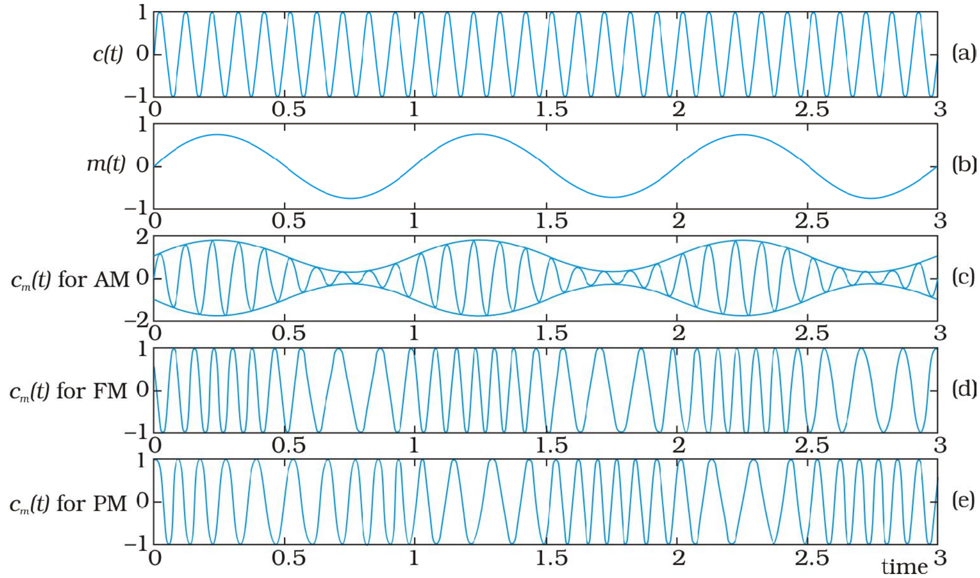

FIGURE 15.8 Modulation of a carrier wave: (a) a sinusoidal carrier wave; (b) a modulating signal; (c) amplitude modulation; (d) frequency modulation; and (e) phase modulation.

Modulation and Demodulation
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Similarly, the significant characteristics of a pulse are: pulse amplitude, pulse duration or pulse Width, and pulse position (denoting the time of *rise* or *fall* of the pulse amplitude) as shown in Fig. 15.7(b). Hence, different types of pulse modulation are: (a) pulse amplitude modulation (PAM), (b) pulse duration modulation (PDM) or pulse width modulation (PWM), and (c) pulse position modulation (PPM). In this chapter, we shall confine to amplitude modulation on ly.

15.8 Amplitude Modulation

In amplitude modulation the amplitude of the carrier is varied in accordance with the information signal. Here we explain amplitude modulation process using a sinusoidal signal as the modulating signal.

Let $c(t) = A_c \sin \omega_c t$ represent carrier wave and $m(t) = A_m \sin \omega_m t$ represent the message or the modulating signal where $\omega_m = 2\pi f_m$ is the angular frequency of the message signal. The modulated signal $c_m(t)$ can be written as

$$c_m(t) = (A_c + A_m \sin \omega_m t) \sin \omega_c t$$

$$= A_c \left(1 + \frac{A_m}{A_c} \sin \omega_m t\right) \sin \omega_c t \tag{15.3}$$

Note that the modulated signal now contains the message signal. This can also be seen from Fig. 15.8(c). From Eq. (15.3), we can write,

$$c_m(t) = A_c \sin \omega_c t + \mu A_c \sin \omega_m t \sin \omega_c t \tag{15.4}$$

Here $\mu = A_m / A_c$ is the *modulation index;* in practice, μ is kept ≤ 1 to avoid distortion.

Using the trignomatric relation $\sin A \sin B$ = ½(cos(A B) $A + B$), we can write c_m (t) of Eq. (15.4) as

$$c_m(t) = A_c \sin \omega_c t + \frac{\mu A_c}{2} \cos(\omega_c - \omega_m)\, t - \frac{\mu A_c}{2} \cos(\omega_c + \omega_m) t \qquad (15.5)$$

Here ω_c ω_m and $\omega_c + \omega_m$ are respectively called the lower side and upper side frequencies. The modulated signal now consists of the carrier wave of frequency ω_c plus two sinusoidal waves each with a frequency slightly different from, known as side bands. The frequency spectrum of the amplitude modulated signal is shown in Fig. 15.9.

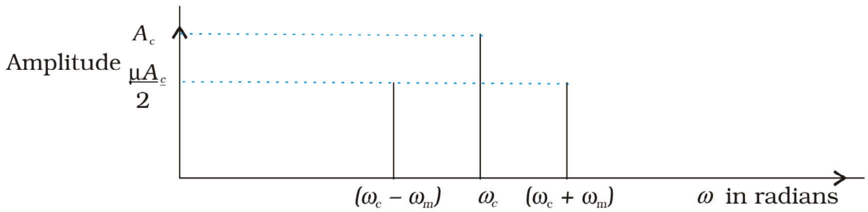


FIGURE 15.9 A plot of amplitude versus ω for an amplitude modulated signal.

As long as the broadcast frequencies (carrier waves) are sufficiently spaced out so that sidebands do not overlap, different stations can operate without interfering with each other.

Example 15.2 A message signal of frequency 10 kHz and peak voltage of 10 volts is used to modulate a carrier of frequency 1 MHz and peak voltage of 20 volts. Determine (a) modulation index, (b) the side bands produced.

Solution

(a) Modulation index =10/20 = 0.5

(b) The side bands are at (1000+10 kHz)=1010 kHz and (1000

EXAMPLE 15.2

15.9 Production of Amplitude Modulated Wave

Amplitude modulation can be produced by a variety of methods. A conceptually simple method is shown in the block diagram of Fig. 15.10.

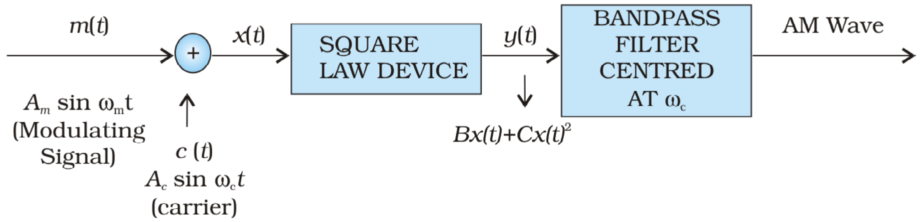


FIGURE 15.10 Block diagram of a simple modulator for obtaining an AM signal.

Here the modulating signal A_m sin $\omega_m t$ is added to the carrier signal A_c sin $\omega_c t$ to produce the signal x (t). This signal x (t) = A_m sin$\omega_m t$ + A_c sin$\omega_c t$ is passed through a square law device which is a non-linear device which produces an output

$$y\,(t) = B\,x\,(t) + Cx^2\,(t) \tag{15.6}$$

where B and C are constants. Thus,

$$y\,(t) = BA_m \sin \omega_m t + BA_c \sin \omega_c t$$

$$+C\left[A_m^2 \sin^2 \omega_m t + A_c^2 \sin^2 \omega_c t + 2A_m A_c \sin \omega_m t \sin \omega_c t\right] \tag{15.7}$$

$$= BA_m \sin \omega_m t + BA_c \sin \omega_c t$$

$$+\frac{C\,A_m^2}{2} + A_c^2 \quad \frac{C\,A_m^2}{2} \qquad \omega_m t \quad \frac{C\,A_c^2}{2} \qquad \omega_c t$$

$$+ CA_m A_c \cos(\omega_c \quad \omega_m)\,t \quad CA_m A_c \cos(\omega_c + \omega_m)\,t \tag{15.8}$$

where the trigonometric relations sin^2A = (1 $\quad$ A)/2 and the relation for sin$A$ sin$B$ mentioned earlier are used.

In Eq. (15.8), there is a dc term $C/2\left(A_m^2 + A_c^2\right)$ and sinusoids of frequencies ω_m, $2\omega_m$, ω_c, $2\omega_c$, $\omega_c \quad \omega_m$ and $\omega_c + \omega_m$. As shown in Fig. 15.10 this signal is passed through a band pass filter* which rejects dc and the sinusoids of frequencies ω_m , $2\omega_m$ and 2 ω_c and retains the frequencies ω_c, $\omega_c \quad \omega_m$ and $\omega_c + \omega_m$. The output of the band pass filter therefore is of the same form as Eq. (15.5) and is therefore an AM wave.

It is to be mentioned that the modulated signal cannot be transmitted as such. The modulator is to be followed by a power amplifier which provides the necessary power and then the modulated signal is fed to an antenna of appropriate size for radiation as shown in Fig. 15.11.

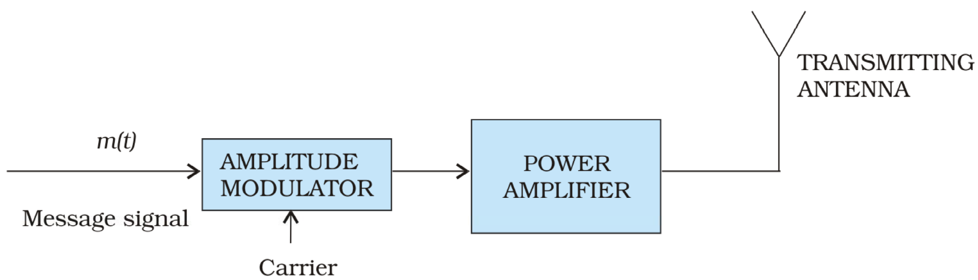


FIGURE 15.11 Block diagram of a transmitter.

15.10 Detection of Amplitude Modulated Wave

The transmitted message gets attenuated in propagating through the channel. The receiving antenna is therefore to be followed by an amplifier and a detector. In addition, to facilitate further processing, the carrier frequency is usually changed to a lower frequency by what is called an *intermediate frequency (IF) stage* preceding the detection. The detected signal may not be strong enough to be made use of and hence is required

* A band pass filter rejects low and high frequencies and allows a band of frequencies to pass through.

to be amplified. A block diagram of a typical receiver is shown in Fig. 15.12

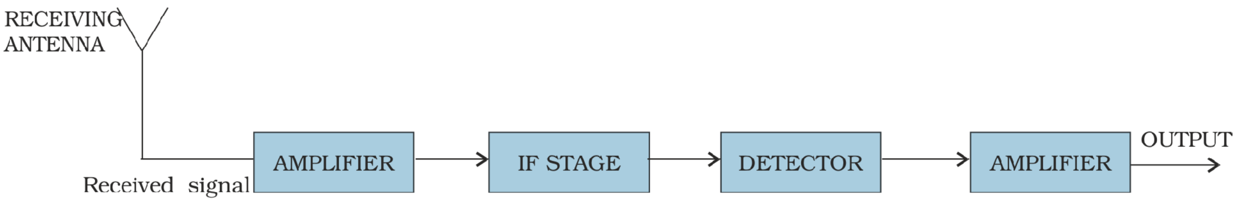


FIGURE 15.12 Block diagram of a receiver.

Detection is the process of recovering the modulating signal from the modulated carrier wave. We just saw that the modulated carrier wave contains the frequencies ω_c and $\omega_c \pm \omega_m$. In order to obtain the original message signal $m(t)$ of angular frequency ω_m, a simple method is shown in the form of a block diagram in Fig. 15.13.

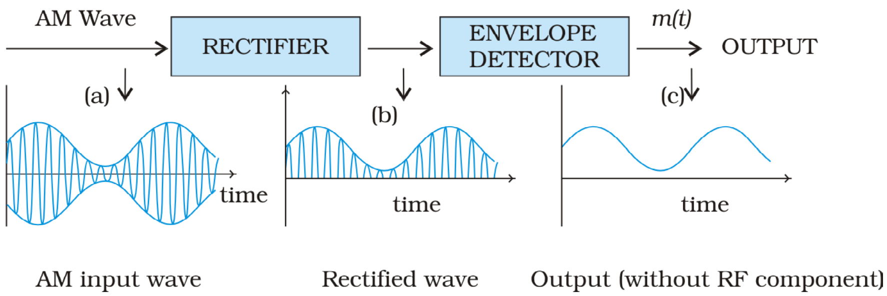


FIGURE 15.13 Block diagram of a detector for AM signal. The quantity on y-axis can be current or voltage.

The modulated signal of the form given in (a) of fig. 15.13 is passed through a rectifier to produce the output shown in (b). This envelope of signal (b) is the message signal. In order to retrieve $m(t)$, the signal is passed through an envelope detector (which may consist of a simple RC circuit).

In the present chapter we have discussed some basic concepts of communication and communication systems. We have also discussed one specific type of analog modulation namely Amplitude Modulation (AM). Other forms of modulation and digital communication systems play an important role in modern communication. These and other exciting developments are taking place everyday.

So far we have restricted our discussion to some basic communication systems. Before we conclude this chapter, it is worth taking a glance at some of the communication systems (see the box) that in recent times have brought major changes in the way we exchange information even in our day-to-day life:

ADDITIONAL INFORMATION

The Internet

It is a system with billions of users worldwide. It permits communication and sharing of all types of information between any two or more computers connected through a large and complex network. It was started in 1960
passage of time it has witnessed tremendous growth and it is still expanding its reach. Its applications include

(i) *E mail*
letter and send it to the recipient through ISP
the dispatching and receiving post offices.

(ii) *File transfer*
computer to another connected to the Internet.

(iii) *World Wide Web (WWW)*
provide *websites* either directly or through web service providers. Government departments, companies, NGO
information about their activities for restricted or free use on their websites. This information becomes accessible to the users. Several search engines like Google, Yahoo! etc. help us in finding information by listing the related websites. *Hypertext* is a powerful feature of the web that automatically links relevant information from one page on the web to another using *HTML (hypertext markup language)*.

(iv) *E-commerce*
using credit cards is called E-commerce. Customers view images and receive all the information about various products or services of companies through their websites. They can do *on-line shopping* from home/office. Goods are dispatched or services are provided by the company through mail/courier.

(v) *Chat*
messages is called chat. Everyone belonging to the *chat group* gets the message instantaneously and can respond rapidly.

Facsimile (FAX)

It scans the contents of a document (as an image, not text) to create electronic signals. These signals are then sent to the destination (another FAX machine) in an orderly manner using telephone lines. At the destination, the signals are reconverted into a replica of the original document. Note that FAX provides image of a static document unlike the image provided by television of objects that might be dynamic.

Mobile telephony

The concept of mobile telephony was developed first in 1970
the following decade. The central concept of this system is to divide the service area into a suitable number of *cells* centred on an office called *MTSO (Mobile Telephone Switching Office)*. Each cell contains a low-power transmitter called a *base station* and caters to a large number of mobile receivers (popularly called cell phones). Each cell could have a service area of a few square kilometers or even less depending upon the number of customers. When a mobile receiver crosses the coverage area of one base station, it is necessary for the mobile user to be transferred to another base station. This procedure is called *handover* or *handoff*. This process is carried out very rapidly, to the extent that the consumer does not even notice it. Mobile telephones operate typically in the UHF range of frequencies (about 800-950 MHz).

SUMMARY

1. Electronic communication refers to the faithful transfer of information or message (available in the form of electrical voltage and current) from one point to another point.
2. Transmitter, transmission channel and receiver are three basic units of a communication system.
3. Two important forms of communication system are: Analog and Digital. The information to be transmitted is generally in continuous waveform for the former while for the latter it has only discrete or quantised levels.
4. Every message signal occupies a range of frequencies. The bandwidth of a message signal refers to the band of frequencies, which are necessary for satisfactory transmission of the information contained in the signal. Similarly, any practical communication system permits transmission of a range of frequencies only, which is referred to as the bandwidth of the system.
5. Low frequencies cannot be transmitted to long distances. Therefore, they are superimposed on a high frequency carrier signal by a process known as modulation.
6. In modulation, some characteristic of the carrier signal like amplitude, frequency or phase varies in accordance with the modulating or message signal. Correspondingly, they are called Amplitude Modulated (AM), Frequency Modulated (FM) or Phase Modulated (PM) waves.
7. Pulse modulation could be classified as: Pulse Amplitude Modulation (PAM), Pulse Duration Modulation (PDM) or Pulse Width Modulation (PWM) and Pulse Position Modulation (PPM).
8. For transmission over long distances, signals are radiated into space using devices called antennas. The radiated signals propagate as electromagnetic waves and the mode of propagation is influenced by the presence of the earth and its atmosphere. Near the surface of the earth, electromagnetic waves propagate as surface waves. Surface wave propagation is useful up to a few MHz frequencies.
9. Long distance communication between two points on the earth is achieved through reflection of electromagnetic waves by ionosphere. Such waves are called sky waves. Sky wave propagation takes place up to frequency of about 30 MHz. Above this frequency, electromagnetic waves essentially propagate as space waves. Space waves are used for line-of-sight communication and satellite communication.
10. If an antenna radiates electromagnetic waves from a height h_T, then the range d_T is given by $\sqrt{2Rh_T}$ where R is the radius of the earth.
11. Amplitude modulated signal contains frequencies $(\omega_c - \omega_m)$, ω_c and $(\omega_c + \omega_m)$.
12. Amplitude modulated waves can be produced by application of the message signal and the carrier wave to a non-linear device, followed by a band pass filter.
13. AM detection, which is the process of recovering the modulating signal from an AM waveform, is carried out using a rectifier and an envelope detector.

POINTS TO PONDER

1. In the process of transmission of message/ information signal, noise gets added to the signal anywhere between the information source and the receiving end. Can you think of some sources of noise?
2. In the process of modulation, new frequencies called sidebands are generated on either side (higher and lower than the carrier frequency) of the carrier by an amount equal to the highest modulating frequency. Is it possible to retrieve the message by transmitting (a) only the side bands, (b) only one side band?
3. In amplitude modulation, modulation index $\mu \leq 1$ is used. What will happen if $\mu > 1$?

EXERCISES

15.1 Which of the following frequencies will be suitable for beyond-the-horizon communication using sky waves?
(a) 10 kHz
(b) 10 MHz
(c) 1 GHz
(d) 1000 GHz

15.2 Frequencies in the UHF range normally propagate by means of:
(a) Ground waves.
(b) Sky waves.
(c) Surface waves.
(d) Space waves.

15.3 Digital signals
(i) do not provide a continuous set of values,
(ii) represent values as discrete steps,
(iii) can utilize binary system, and
(iv) can utilize decimal as well as binary systems.
Which of the above statements are true?
(a) (i) and (ii) only
(b) (ii) and (iii) only
(c) (i), (ii) and (iii) but not (iv)
(d) All of (i), (ii), (iii) and (iv).

15.4 Is it necessary for a transmitting antenna to be at the same height as that of the receiving antenna for line-of-sight communication? A TV transmitting antenna is 81m tall. How much service area can it cover if the receiving antenna is at the ground level?

15.5 A carrier wave of peak voltage 12V is used to transmit a message signal. What should be the peak voltage of the modulating signal in order to have a modulation index of 75%?

15.6 A modulating signal is a square wave, as shown in Fig. 15.14.

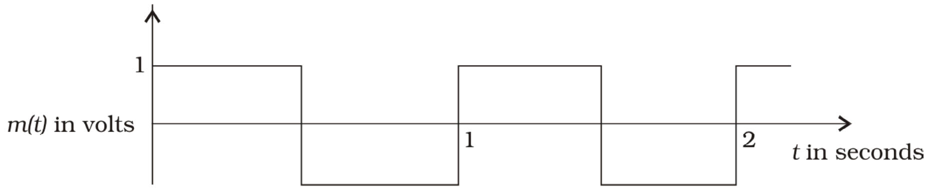


FIGURE 15.14

The carrier wave is given by $c(t) = 2\sin(8\pi t)$ volts.

(i) Sketch the amplitude modulated waveform

(ii) What is the modulation index?

15.7 For an amplitude modulated wave, the maximum amplitude is found to be 10V while the minimum amplitude is found to be 2V. Determine the modulation index, μ.
What would be the value of μ if the minimum amplitude is zero volt?

15.8 Due to economic reasons, only the upper sideband of an AM wave is transmitted, but at the receiving station, there is a facility for generating the carrier. Show that if a device is available which can multiply two signals, then it is possible to recover the modulating signal at the receiver station.

APPENDICES

APPENDIX A 1

THE GREEK ALPHABET

Alpha	A	α	Iota	I	ι	Rho	P	ρ
Beta	B	β	Kappa	K	κ	Sigma	Σ	σ
Gamma	Γ	γ	Lambda	Λ	λ	Tau	T	τ
Delta	Δ	δ	Mu	M	μ	Upsilon	Y	υ
Epsilon	E	ε	Nu	N	ν	Phi	Φ	ϕ, φ
Zeta	Z	ς	Xi	Ξ	ξ	Chi	X	χ
Eta	H	η	Omicron	O	ο	Psi	Ψ	ψ
Theta	Θ	θ	Pi	Π	π	Omega	Ω	ω

APPENDIX A 2

COMMON SI PREFIXES AND SYMBOLS FOR MULTIPLES AND SUB-MULTIPLES

Multiple			Sub-Multiple		
Factor	**Prefix**	**Symbol**	**Factor**	**Prefix**	**symbol**
10^{18}	Exa	E	10^{-18}	atto	a
10^{15}	Peta	P	10^{-15}	femto	f
10^{12}	Tera	T	10^{-12}	pico	p
10^{9}	Giga	G	10^{-9}	nano	n
10^{6}	Mega	M	10^{-6}	micro	μ
10^{3}	kilo	k	10^{-3}	milli	m
10^{2}	Hecto	h	10^{-2}	centi	c
10^{1}	Deca	da	10^{-1}	deci	d

APPENDIX A 3

SOME IMPORTANT CONSTANTS

Name	Symbol	Value
Speed of light in vacuum	c	2.9979×10^{8} m s^{-1}
Charge of electron	e	1.602×10^{-19} C
Gravitational constant	G	6.673×10^{-11} N m^2 kg^{-2}
Planck constant	h	6.626×10^{-34} J s
Boltzmann constant	k	1.381×10^{-23} J K^{-1}
Avogadro number	N_A	6.022×10^{23} mol^{-1}
Universal gas constant	R	8.314 J mol^{-1} K^{-1}
Mass of electron	m_e	9.110×10^{-31} kg
Mass of neutron	m_n	1.675×10^{-27} kg
Mass of proton	m_p	1.673×10^{-27} kg
Electron-charge to mass ratio	e/m_e	1.759×10^{11} C/kg
Faraday constant	F	9.648×10^{4} C/mol
Rydberg constant	R	1.097×10^{7} m^{-1}
Bohr radius	a_0	5.292×10^{-11} m
Stefan-Boltzmann constant	σ	5.670×10^{-8} Wm^{-2}K^{-4}
Wien's Constant	b	2.898×10^{-3} mK
Permittivity of free space	ε_0 $1/4\pi\,\varepsilon_0$	8.854×10^{-12} C^2 N^{-1}m^{-2} 8.987×10^{9} N m^2 C^{-2}
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T m A^{-1} $\cong 1.257 \times 10^{-6}$ Wb A^{-1} m^{-1}

OTHER USEFUL CONSTANTS

Name	Symbol	Value
Mechanical equivalent of heat	J	4.186 J cal^{-1}
Standard atmospheric pressure	1 atm	1.013×10^{5} Pa
Absolute zero	0 K	−273.15 °C
Electron volt	1 eV	1.602×10^{-19} J
Unified Atomic mass unit	1 u	1.661×10^{-27} kg
Electron rest energy	mc^2	0.511 MeV
Energy equivalent of 1 u	1 uc^2	931.5 MeV
Volume of ideal gas(0 °C and 1atm)	V	22.4 L mol^{-1}
Acceleration due to gravity (sea level, at equator)	g	9.78049 m s^{-2}

ANSWERS

Chapter 9

9.1 $v =$ cm. The image is real, inverted and magnified. The size of the image is 5.0 cm. As $u \to f$, $v \to \infty$; for $u < f$, image is virtual.

9.2 $v = 6.7$ cm. Magnification = 5/9, i.e., the size of the image is 2.5 cm. As $u \to \infty$; $v \to f$ (but never beyond) while $m \to 0$.

9.3 1.33; 1.7 cm

9.4 $n_{ga} = 1.51$; $n_{wa} = 1.32$; $n_{gw} = 1.144$; which gives sin $r = 0.6181$ i.e., $r \simeq 38^o$.

9.5 $r = 0.8 \times \tan i_c$ and $\sin i_c = 1/1.33 \cong 0.75$, where r is the radius (in m) of the largest circle from which light comes out and i_c is the critical angle for water-air interface, Area = 2.6 m^2

9.6 $n \cong 1.53$ and D_m for prism in water $\cong 10^o$

9.7 $R = 22$ cm

9.8 Here the object is virtual and the image is real. $u = +12$ cm (object on right; virtual)

(a) $f = +20$ cm. Image is real and at 7.5 cm from the lens on its right side.

(b) $f =$ cm. Image is real and at 48 cm from the lens on its right side.

9.9 $v = 8.4$ cm, image is erect and virtual. It is diminished to a size 1.8 cm. As $u \to \infty$, $v \to f$ (but never beyond f while $m \to 0$).

Note that when the object is placed at the focus of the concave lens (21 cm), the image is located at 10.5 cm (not at infinity as one might wrongly think).

9.10 A diverging lens of focal length 60 cm

9.11 (a) $v_e =$ cm and $f_e = 6.25$ cm give $u_e =$ cm; $v_O =$ (15 cm = 10 cm,

$f_O = u_O =$ cm; Magnifying power = 20

(b) $u_O =$ cm.

Magnifying power = 13.5.

9.12 Angular magnification of the eye-piece for image at 25 cm

$$= \frac{25}{2.5} + 1 = 11; \ |u_e| = \frac{25}{11} \text{cm} = 2.27 \text{cm}; \ v_O = 7.2 \text{cm}$$

Separation = 9.47 cm; Magnifying power = 88

9.13 24; 150 cm

9.14 (a) Angular magnification = 1500

(b) Diameter of the image = 13.7 cm.

9.15 Apply mirror equation and the condition:

(a) $f < 0$ (concave mirror); $u < 0$ (object on left)

(b) $f > 0$; $u < 0$

(c) $f > 0$ (convex mirror) and $u < 0$

(d) $f < 0$ (concave mirror); $f < u < 0$

to deduce the desired result.

9.16 The pin appears raised by 5.0 cm. It can be seen with an explicit ray diagram that the answer is independent of the location of the slab (for small angles of incidence).

9.17 (a) $\sin i_c' = 1.44/1.68$ which gives $i_c' = 59°$. Total internal reflection takes place when $i > 59°$ or when $r < r_{max} = 31°$. Now, $(\sin i_{max} / \sin r_{max}) = 1.68$, which gives $i_{max} \simeq 60°$. Thus, all incident rays of angles in the range $0 < i < 60°$ will suffer total internal reflections in the pipe. (If the length of the pipe is finite, which it is in practice, there will be a lower limit on i determined by the ratio of the diameter to the length of the pipe.)

(b) If there is no outer coating, $i_c' = \sin$ $(1/1.68) = 36.5°$. Now, $i = 90°$ will have $r = 36.5°$ and $i' = 53.5°$ which is greater than i_c'. Thus, *all* incident rays (in the range $53.5° < i < 90°$) will suffer total internal reflections.

9.18 (a) Rays converging to a point reflected to a point in front of the mirror on a screen. In other words, a plane or convex mirror can produce a real image if the object is virtual. Convince yourself by drawing an appropriate ray diagram.

(b) When the reflected or refracted rays are divergent, the image is virtual. The divergent rays can be converged on to a screen by means of an appropriate converging lens. The convex lens of the eye does just that. The virtual image here serves as an object for the lens to produce a real image. Note, the screen here is not located at the position of the virtual image. There is no contradiction.

(c) Taller

(d) The apparent depth for oblique viewing decreases from its value for near-normal viewing. Convince yourself of this fact by drawing ray diagrams for different positions of the observer.

(e) Refractive index of a diamond is about 2.42, much larger than that of ordinary glass (about 1.5). The critical angle of diamond is about 24°, much less than that of glass. A skilled diamond-cutter exploits the larger range of angles of incidence (in the diamond), 24° to 90°, to ensure that light entering the diamond is totally reflected from many faces before getting out producing a sparkling effect.

9.19 For fixed distance s between object and screen, the lens equation does not give a real solution for u or v if f is greater than $s/4$.

Therefore, $f_{max} = 0.75$ m.

9.20 21.4cm

9.21 (a) (i) Let a parallel beam be the incident from the left on the convex lens first.

$f_1 = 30$ cm and $u_1 = \infty$, give $v_1 = +30$ cm. This image becomes a virtual object for the second lens.

$f_2 =$ cm, $u_2 = +(30$ cm $= +22$ cm which gives, $v_2 =$ cm. The parallel incident beam appears to diverge from a point 216 cm from the centre of the two-lens system.

(ii) Let the parallel beam be incident from the left on the concave lens first: $f_1 =$ cm, $u_1 = \infty$, give $v_1 =$ cm. This image becomes a real object for the second lens: $f_2 = +30$ cm, $u_2 =$ cm $=$ cm which gives, $v_2 =$ cm. The parallel incident beam appears to diverge from a point 416 cm on the left of the centre of the two-lens system.

Clearly, the answer depends on which side of the lens system the parallel beam is incident. *Further we do not have a simple lens equation true for all u (and v) in terms of a definite constant of the system (the constant being determined by* f_1 *and* f_2*, and the separation between the lenses).* The notion of effective focal length, therefore, does not seem to be meaningful for this system.

(b) $u_1 =$ cm, $f_1 = 30$ cm, gives $v_1 = 120$ cm.

Magnitude of magnification due to the first (convex) lens is 3.
$u_2 = +(120$ cm $= +112$ cm (object virtual);

$f_2 =$ $\qquad v_2 = -\dfrac{112 \times 20}{92}$ cm

Magnitude of magnification due to the second (concave) lens = 20/92.

Net magnitude of magnification = 0.652

Size of the image = 0.98 cm

9.22 If the refracted ray in the prism is incident on the second face at the critical angle i_c, the angle of refraction r at the first face is $(60°\ i_c)$.

Now, $i_c = \sin\ (1/1.524) \simeq 41°$

Therefore, $r = 19°$

$\sin i =\ 0.4962$; $i \simeq 30°$

9.23 Two identical prisms made of the same glass placed with their bases on opposite sides (of the incident white light) and faces touching (or parallel) will neither deviate nor disperse, but will mearly produce a parallel displacement of the beam.

(a) To deviate without dispersion, choose, say, the first prism to be of crown glass, and take for the second prism a flint glass prism of suitably chosen refracting angle (smaller than that of crown glass prism because the flint glass prism disperses more) so that dispersion due to the first is nullified by the second.

(b) To disperse without deviation, increase the angle of flint glass prism (i.e., try flint glass prisms of greater and greater angle) so that deviations due to the two prisms are equal and opposite. (The flint glass prism angle will still be smaller than that of crown glass because flint glass has higher refractive index than that of crown glass). Because of the adjustments involved for so many colours, these are not meant to be precise arrangements for the purpose required.

9.24 To see objects at infinity, the eye uses its least converging power = (40+20) dioptres = 60 dioptres. This gives a rough idea of the distance between the retina and cornea-eye lens: (5/3) cm. To focus an object at the near point ($u =$ cm), on the retina (v = 5/3 cm), the focal length should be

$$\left[\frac{1}{25}+\frac{3}{5}\right]^{-1}=\frac{25}{16}\text{cm}$$

corresponding to a converging power of 64 dioptres. The power of the eye lens then is (64
accommodation of the eye-lens is roughly 20 to 24 dioptres.

9.25 No, a person may have normal ability of accommodation of the eye-lens and yet may be myopic or hypermetropic. Myopia arises when the eye-ball from front to back gets too elongated; hypermetropia arises when it gets too shortened. In practice, in addition, the eye lens may also lose some of its ability of accommodation. When the eyeball has the normal length but the eye lens loses partially its ability of accommodation (as happens with increasing age for any normal eye), the
same manner as hypermetropia.

9.26 The far point of the person is 100 cm, while his near point may have been normal (about 25 cm). Objects at infinity produce virtual image at 100 cm (using spectacles). To view closer objects i.e., those which are (or whose images using the spectacles are) between 100 cm and 25 cm, the person uses the ability of accommodation of his eye-lens. This ability usually gets partially lost in old age (presbyopia). The near point of the person recedes to 50 cm. To view objects at 25 cm clearly, the person needs converging lens of power +2 dioptres.

9.27 The defect (called astigmatism) arises because the curvature of the cornea plus eye-lens refracting system is not the same in different planes. [The eye-lens is usually spherical i.e., has the same curvature on different planes but the cornea is not spherical in case of an astigmatic eye.] In the present case, the curvature in the vertical plane is enough, so sharp images of vertical lines can be formed on the retina. But the curvature is insufficient in the horizontal plane, so horizontal lines appear blurred. The defect can be corrected by using a cylindrical lens with its axis along the vertical. Clearly, parallel rays in the vertical plane will suffer no extra refraction, but those in the horizontal plane can get the required extra convergence due to refraction by the curved surface of the cylindrical lens if the curvature of the cylindrical surface is chosen appropriately.

9.28 (a) Closest distance = $4\frac{1}{6}\text{cm} \approx 4.2\text{cm}$

Farthest distance = 5 cm

(b) Maximum angular magnification = [25/(25/6)] = 6. Minimum angular magnification = (25/5) = 5

9.29 (a) $\frac{1}{v}+\frac{1}{9}=\frac{1}{10}$

i.e., $v =$ cm,

Magnitude of magnification = 90/9 = 10.

Each square in the virtual image has an area 10 x 10 x 1 mm^2 = 100 mm^2 = 1 cm^2

(b) Magnifying power = 25/9 = 2.8

(c) No, magnification of an image by a lens and angular magnification (or magnifying power) of an optical instrument are two separate things. The latter is the ratio of the angular size of the object (which is equal to the angular size of the image even if the image is magnified) to the angular size of the object if placed at the near point (25 cm). Thus, magnification magnitude is $|(v/u)|$ and magnifying power is $(25/\ |u|)$. Only when the image is located at the near point $|v|$ = 25 cm, are the two quantities equal.

9.30 (a) Maximum magnifying power is obtained when the image is at the near point (25 cm)

u =   cm.

(b) Magnitude of magnification = $(25/\ |u|)$ = 3.5.

(c) Magnifying power = 3.5

Yes, the magnifying power (when the image is produced at 25 cm) is equal to the magnitude of magnification.

9.31 Magnification = $\sqrt{(6.25 / 1)}$ = 2.5

$v = +2.5u$

$$+\frac{1}{2.5u} - \frac{1}{u} = \frac{1}{10}$$

i.e., u =   cm

$|v|$ = 15 cm

The virtual image is closer than the normal near point (25 cm) and cannot be seen by the eye distinctly.

9.32 (a) Even though the absolute image size is bigger than the object size, the angular size of the image is equal to the angular size of the object. The magnifier helps in the following way: without it object would be placed no closer than 25 cm; with it the object can be placed much closer. The closer object has larger angular size than the same object at 25 cm. It is in this sense that angular magnification is achieved.

(b) Yes, it decreases a little because the angle subtended at the eye is then slightly less than the angle subtended at the lens. The effect is negligible if the image is at a very large distance away. [*Note:* When the eye is separated from the lens, the angles subtended at the eye by the first object and its image are not equal.]

(c) First, grinding lens of very small focal length is not easy. More important, if you decrease focal length, aberrations (both spherical and chromatic) become more pronounced. So, in practice, you cannot get a magnifying power of more than 3 or so with a simple convex lens. However, using an aberration corrected lens system, one can increase this limit by a factor of 10 or so.

(d) Angular magnification of eye-piece is $[(25/f_e) + 1]$ (f_e in cm) which increases if f_e is smaller. Further, magnification of the objective

is given by $$\frac{v_O}{|u_O|} = \frac{1}{(|u_O|/f_O) - 1}$$

which is large when $|u_O|$ is slightly greater than f_O. The microscope is used for viewing very close object. So $|u_O|$ is small, and so is f_O.

(e) The image of the objective in the eye-piece is known as e-ring. All the rays from the object refracted by objective go through the eye-ring. Therefore, it is an ideal position for our eyes for viewing. If we place our eyes too close to the eye-piece, we shall not collect much of the light and also reduce our field of view. If we position our eyes on the eye-ring and the area of the pupil of our eye is greater or equal to the area of the eye-ring, our eyes will collect all the light refracted by the objective. The precise location of the eye-ring naturally depends on the separation between the objective and the eye-piece. When you view through a microscope by placing your eyes on one end,the ideal distance between the eyes and eye-piece is usually built-in the design of the instrument.

9.33 Assume microscope in normal use i.e., image at 25 cm. Angular magnification of the eye-piece

$$= \frac{25}{5} + 1 = 6$$

Magnification of the objective

$$= \frac{30}{6} = 5$$

$$\frac{1}{5u_O} - \frac{1}{u_O} = \frac{1}{1.25}$$

which gives $u_O =$ cm; $v_0 = 7.5$ cm. $|u_e| = (25/6)$ cm = 4.17 cm. The separation between the objective and the eye-piece should be (7.5 + 4.17) cm = 11.67 cm. Further the object should be placed 1.5 cm from the objective to obtain the desired magnification.

9.34 (a) $m = (f_O/f_e) = 28$

(b) $m = \dfrac{f_O}{f_e}\left[1 + \dfrac{f_O}{25}\right] = 33.6$

9.35 (a) $f_O + f_e = 145$ cm

(b) Angle subtended by the tower = (100/3000) = (1/30) rad.

Angle subtended by the image produced by the objective

$$= \frac{h}{f_O} = \frac{h}{140}$$

Equating the two, $h = 4.7$ cm.

(c) Magnification (magnitude) of the eye-piece = 6. Height of the final image (magnitude) = 28 cm.

9.36 The image formed by the larger (concave) mirror acts as virtual object for the smaller (convex) mirror. Parallel rays coming from the object at infinity will focus at a distance of 110 mm from the larger mirror. The distance of virtual object for the smaller mirror = (110 20) = 90 mm. The focal length of smaller mirror is 70 mm. Using the mirror formula, image is formed at 315 mm from the smaller mirror.

9.37 The reflected rays get deflected by twice the angle of rotation of the mirror. Therefore, $d/1.5 = \tan 7°$. Hence d = 18.4 cm.

9.38 $n = 1.33$

CHAPTER 10

10.1 (a) Reflected light: (wavelength, frequency, speed same as incident light)

λ = 589 nm, $\nu = 5.09 \times 10^{14}$ Hz, $c = 3.00 \times 10^{8}$ m s

(b) Refracted light: (frequency same as the incident frequency)
$\nu = 5.09 \times 10^{14}$Hz
$v = (c/n) = 2.26 \times 10^{8}$ m s , $\lambda = (v/\nu)$ = 444 nm

10.2 (a) Spherical
(b) Plane
(c) Plane (a small area on the surface of a large sphere is nearly planar).

10.3 (a) 2.0×10^{8} m s
(b) No. The refractive index, and hence the speed of light in a medium, depends on wavelength. [When no particular wavelength or colour of light is specified, we may take the given refractive index to refer to yellow colour.] Now we know violet colour deviates more than red in a glass prism, i.e. $n_v > n_r$. Therefore, the violet component of white light travels slower than the red component.

10.4 $$\lambda = \frac{1.2\times10 \quad \times0.28\times10}{4\times1.4} \text{ m} = 600 \text{ nm}$$

10.5 K/4

10.6 (a) 1.17 mm (b) 1.56 mm

10.7 0.15°

10.8 tan (1.5) $\simeq$ 56.3°

10.9 5000 Å, 6×10^{14} Hz; 45°

10.10 40 m

10.11 Use the formula $\lambda' \quad \lambda = \frac{v}{c}\lambda$

$$\text{i.e., } v = \frac{c}{\lambda}(\lambda' - \lambda) = \frac{3\times10^{8}\times15}{6563} = 6.86 \times 10^{5} \text{ m s}$$

10.12 In corpuscular (particle) picture of refraction, particles of light incident from a rarer to a denser medium experience a force of attraction normal to the surface. This results in an increase in the normal component of the velocity but the component along the surface is unchanged. This means

$$c \sin i = v \sin r \quad \text{or} \quad \frac{v}{c} = \frac{\sin i}{\sin r} = n. \text{ Since } n > 1, v > c.$$

The prediction is *opposite* to the experimental results ($v < c$). The wave picture of light is consistent with the experiment.

10.13 With the point object at the centre, draw a circle touching the mirror. This is a plane section of the spherical wavefront from the object that has just reached the mirror. Next draw the locations of this same wavefront after a time t in the presence of the mirror, and in the absence of the mirror. You will get two arcs symmetrically located on either side of the mirror. Using simple geometry, the centre of the reflected wavefront (the image of the object) is seen to be at the same distance from the mirror as the object.

10.14 (a) The speed of light in vacuum is a universal constant independent of all the factors listed and anything else. In particular, note the surprising fact that it is independent of the relative motion between the source and the observer. This fact is a basic axiom of Einstein

(b) Dependence of the speed of light in a medium:

(i) does not depend on the nature of the source (wave speed is determined by the properties of the medium of propagation. This is also true for other waves, e.g., sound waves, water waves, etc.).

(ii) independent of the direction of propagation for *isotropic* media.

(iii) independent of the motion of the source relative to the medium but depends on the motion of the observer relative to the medium.

(iv) depends on wavelength.

(v) independent of intensity. [For high intensity beams, however, the situation is more complicated and need not concern us here.]

10.15 Sound waves require a medium for propagation. Thus even though the situations (i) and (ii) may correspond to the same relative motion (between the source and the observer), they are not identical physically since the motion of the observer *relative to the medium* is different in the two situations. Therefore, we cannot expect Doppler formulas for sound to be identical for (i) and (ii). For light waves in vacuum, there is clearly nothing to distinguish between (i) and (ii). Here only the relative motion between the source and the observer counts and the relativistic Doppler formula is the same for (i) and (ii). For light propagation in a medium, once again like for sound waves, the two situations are *not* identical and we should expect the Doppler formulas for this case to be different for the two situations (i) and (ii).

10.16 3.4×10^{4} m.

10.17 (a) The size reduces by half according to the relation: size ~ λ/d. Intensity increases four fold.

(b) The intensity of interference fringes in a double-slit arrangement is modulated by the diffraction pattern of each slit.

(c) Waves diffracted from the edge of the circular obstacle interfere constructively at the centre of the shadow producing a bright spot.

(d) For diffraction or bending of waves by obstacles/apertures by a large angle, the size of the latter should be comparable to wavelength. If the size of the obstacle/aperture is much too large compared to wavelength, diffraction is by a small angle. Here the size is of the order of a few metres. The wavelength of light is about 5×10 m, while sound waves of, say, 1 kHz frequency have wavelength of about 0.3 m. Thus, sound waves can bend around the partition while light waves cannot.

(e) Justification based on what is explained in (d). Typical sizes of apertures involved in ordinary optical instruments are much larger than the wavelength of light.

10.18 12.5 cm.

10.19 0.2 nm.

10.20 (a) Interference of the direct signal received by the antenna with the (weak) signal reflected by the passing aircraft.

(b) Superposition principle follows from the linear character of the (differential) equation governing wave motion. If y_1 and y_2 are solutions of the wave equation, so is any linear combination of y_1 and y_2. When the amplitudes are large (e.g., high intensity laser beams) and non-linear effects are important, the situation is far more complicated and need not concern us here.

10.21 Divide the single slit into n smaller slits of width $a' = a/n$. The angle $\theta = n\lambda/a = \lambda/a'$. Each of the smaller slits sends zero intensity in the direction θ. The combination gives zero intensity as well.

CHAPTER 11

11.1 (a) 7.24×10^{18} Hz (b) 0.041 nm

11.2 (a) 0.34 eV = 0.54×10 J (b) 0.34 V (c) 344 km/s

11.3 1.5 eV = 2.4×10 J

11.4 (a) 3.14×10 J, 1.05×10 kg m/s (b) 3×10^{16} photons/s

(c) 0.63 m/s

11.5 4×10^{21} photons/m^2 s

11.6 6.59×10 Js

11.7 (a) 3.38×10 J = 2.11 eV (b) 3.0×10^{20} photons/s

11.8 2.0 V

11.9 No, because $\nu < \nu_o$

11.10 4.73×10^{14} Hz

11.11 2.16 eV = 3.46×10 J

11.12 (a) 4.04×10 kg m s (b) 0.164 nm

11.13 (a) 5.92×10 kg m s (b) 6.50×10^6 m s (c) 0.112 nm

11.14 (a) 6.95×10 J = 4.34 μeV (b) 3.78×10 J = 0.236 neV

11.15 (a) 1.7×10 m (b) 1.1×10 m (c) 3.0×10 m

11.16 (a) 6.63×10 kg m/s (for both) (b) 1.24 keV (c) 1.51 eV

11.17 (a) 6.686×10 J = 4.174×10 eV (b) 0.145 nm

11.18 $\lambda = h/p = h/(h\nu/c) = c/\nu$

11.19 0.028 nm

11.20 (a) Use $eV = (m\,v^2/2)$ i.e., $v = [(2eV/m)]^{1/2}$; $v = 1.33 \times 10^7$ m s .

(b) If we use the same formula with $V = 10^7$ V, we get $v = 1.88 \times 10^9$ m s . This is clearly wrong, since nothing can move with a speed greater than the speed of light ($c = 3 \times 10^8$ m s). Actually, the above formula for kinetic energy $(m\,v^2/2)$ is valid only when

(v/c) << 1. At very high speeds when (v/c) is comparable to (though always less than) 1, we come to the relativistic domain where the following formulae are valid:

Relativistic momentum $p = m\,v$

Total energy $E = m\,c^2$

Kinetic energy $K = m\,c^2 \quad m_0\,c^2$,

where the relativistic mass m is given by $m = m_0\left(1 - \dfrac{v^2}{c^2}\right)^{-1/2}$

m_0 is called the rest mass of the particle. These relations also imply:

$E = (p^2c^2 + m_0^2\,c^4)^{1/2}$

Note that in the relativisitc domain when v/c is comparable to 1, K or energy $\geq m_0c^2$ (rest mass energy). The rest mass energy of electron is about 0.51 MeV. Thus a kinetic energy of 10 MeV, being much greater than electron

Using relativistic formulas, v (for 10 MeV kinetic energy) = 0.999 c.

11.21 (a) 22.7cm

(b) No. As explained above, a 20 MeV electron moves at relativistic speed. Consequently, the non-relativistic formula $R = (m_0v/e\,B)$ is not valid. The relativistic formula is

$$R = p/eB = mv/eB \quad \text{or} \quad R = \mathrm{m}_0 v/\left(eB\sqrt{1 \quad v^2 \quad c^2}\right)$$

11.22 We have $e\,V = (m\,v^2/2)$ and $R = (m\,v/e\,B)$ which gives $(e/m) = (2V/R^2B^2)$; using the given data $(e/m) = 1.73 \times 10^{11}$ C kg .

11.23 (a) 27.6 keV (b) of the order of 30 kV

11.24 Use $\lambda = (hc/E)$ with $E = 5.1 \times 1.602 \times 10$ J to get $\lambda = 2.43 \times 10$ m .

11.25 (a) For $\lambda = 500$ m, $E = (h\,c/\lambda) = 3.98 \times 10$ J. Number of photons emitted per second

$= 10^4$J s $/3.98 \times 10$ J $\simeq 3 \times 10^{31}$s

We see that the energy of a radiophoton is exceedingly small, and the number of photons emitted per second in a radio beam is enormously large. There is, therefore, negligible error involved in ignoring the existence of a minimum quantum of energy (photon) and treating the total energy of a radio wave as continuous.

(b) For $\nu = 6 \times 10^{14}$ Hz, $E \simeq 4 \times 10$ J. Photon flux corresponding to minimum intensity

$= 10$ Wm $/4 \times 10$ J $= 2.5 \times 10^8$m s

Number of photons entering the pupil per second $= 2.5 \times 10^8 \times 0.4 \times 10$ s $= 10^4$s . Though this number is not as large as in (a) above, it is large enough for us never to individual photons by our eye.

11.26 $\phi_0 = h\,\nu \quad _0 = 6.7 \times 10$ J = 4.2 eV; $\nu_0 = \dfrac{\phi_0}{h} = 1.0 \times 10^{15}$ Hz; $\lambda = 6328$Å corresponds to $\nu = 4.7 \times 10^{14}$ Hz $< \nu_0$. The photo-cell will not respond howsoever high be the intensity of laser light.

11.27 Use $e\,V_0 = h\,\nu \quad \phi_0$ for both sources. From the data on the first source, $\phi_0 = 1.40$ eV. Use this value to obtain for the second source $V_0 = 1.50$ V.

11.28 Obtain V_0 versus ν plot. The slope of the plot is (h/e) and its intercept on the ν-axis is ν_0. The first four points lie nearly on a straight line which intercepts the ν-axis at $\nu_0 = 5.0 \times 10^{14}$ Hz (threshold frequency). The fifth point corresponds to $\nu < \nu_0$; there is no photoelectric emission and therefore no stopping voltage is required to stop the current. Slope of the plot is found to be 4.15 × 10 V s. Using e = 1.6 × 10 C, h = 6.64 × 10 J s (standard value h = 6.626 × 10 J s), $\phi_0 = h\,\nu_0$ = 2.11V.

11.29 It is found that the given incident frequency ν is greater than ν_0 (Na), and ν_0 (K); but less than ν_0 (Mo), and ν_0 (Ni). Therefore, Mo and Ni will not give photoelectric emission. If the laser is brought closer, intensity of radiation increases, but this does not affect the result regarding Mo and Ni. However, photoelectric current from Na and K will increase in proportion to intensity.

11.30 Assume one conduction electron per atom. Effective atomic area ~10 m^2

Number of electrons in 5 layers

$$= \frac{5 \times 2 \times 10^{-4}\ \text{m}^2}{10^{-20}\ \text{m}^2} = 10^{17}$$

Incident power

= 10 W m × 2 × 10 m^2 = 2 × 10 W

In the wave picture, incident power is uniformly absorbed by all the electrons continuously. Consequently, energy absorbed per second per electron

= 2 × 10 / 10^{17} = 2 × 10 W

Time required for photoelectric emission

= 2 × 1.6 × 10 J / 2 × 10 W = 1.6 × 10^7 s

which is about 0.5 year.

Implication: Experimentally, photoelectric emission is observed nearly instantaneously (~10 s): Thus, the wave picture is in gross disagreement with experiment. In the photon-picture, energy of the radiation is not continuously shared by all the electrons in the top layers. Rather, energy comes in discontinuous
absorption of energy does not take place gradually. A photon is either not absorbed, or absorbed by an electron nearly instantly.

11.31 For λ = 1 Å, electron eV; photon keV. Thus, for the same wavelength, a photon has much greater energy than an electron.

11.32 (a) $\lambda = \dfrac{h}{p} = \dfrac{h}{\sqrt{2\,m\,K}}$ Thus, for same K, λ decreases with m as ($1/\sqrt{m}$). Now (m_n/m_e) = 1838.6; therefore for the same energy, (150 eV) as in Ex. 11.31, wavelength of neutron = $\left(1/\sqrt{1838.6}\right)$ × 10 m = 2.33 × 10 m. The interatomic spacing is about a hundred times greater. A neutron beam of 150 eV energy is therefore not suitable for diffraction experiments.

(b) λ = 1.45 × 10 m [Use $\lambda = (h/\sqrt{3\,m\,k\,T})$] which is comparable to interatomic spacing in a crystal.

Clearly, from (a) and (b) above, thermal neutrons are a suitable probe for diffraction experiments; so a high energy neutron beam should be first thermalised before using it for diffraction.

11.33 $\lambda = 5.5 \times 10$ m

λ (yellow light) $= 5.9 \times 10$ m

Resolving Power (RP) is inversely proportional to wavelength. Thus, RP of an electron microscope is about 10^5 times that of an optical microscope. In practice, differences in other (geometrical) factors can change this comparison somewhat.

11.34 $p = \dfrac{h}{\lambda} = \dfrac{6.63\times 10 \text{ Js}}{10 \text{ m}} = 6.63 \times 10$ kg m s

Use the relativistic formula for energy:

$E^2 = c^2p^2 + m_0^2\, c^4 = 9 \times (6.63)^2 \times 10 \;\; + (0.511 \times 1.6)^2 \times 10$

$\simeq 9 \times (6.63)^2 \times 10$,

the second term (rest mass energy) being negligible.

Therefore, $E = 1.989 \times 10$ J = 1.24 BeV. Thus, electron energies from the accelerator must have been of the order of a few BeV.

11.35 Use $\lambda = \dfrac{h}{\sqrt{3\, m\, k\, T}}$; $m_{He} = \dfrac{4\times 10}{6\times 10^{23}}$ kg

This gives $\lambda = 0.73 \times 10$ m. Mean separation

$r = (V/N)^{1/3} = (kT/p)^{1/3}$

For $T = 300$ K, $p = 1.01 \times 10^5$ Pa, $r = 3.4 \times 10$ m. We find $r >> \lambda$.

11.36 Using the same formula as in Exercise 11.35, $\lambda = 6.2 \times 10$ m which is much greater than the given inter-electron separation.

11.37 (a) Quarks are thought to be confined within a proton or neutron by forces which grow stronger if one tries to pull them apart. It, therefore, seems that though fractional charges may exist in nature, observable charges are still integral multiples of e.

(b) Both the basic relations $e\,V = (1/2)\, m\, v^2$ or $e\,E = m\,a$ and $e\,B\,v = m\,v^2/r$, for electric and magnetic fields, respectively, show that the dynamics of electrons is determined not by e, and m separately but by the combination e/m.

(c) At low pressures, ions have a chance to reach their respective electrodes and constitute a current. At ordinary pressures, ions have no chance to do so because of collisions with gas molecules and recombination.

(d) Work function merely indicates the minimum energy required for the electron in the highest level of the conduction band to get out of the metal. Not all electrons in the metal belong to this level. They occupy a continuous band of levels. Consequently, for the same incident radiation, electrons knocked off from different levels come out with different energies.

(e) The absolute value of energy E (but not momentum p) of any particle is arbitrary to within an additive constant. Hence, while λ is physically significant, absolute value of ν of a matter wave of an electron has no direct physical meaning. The phase speed $\nu\lambda$ is likewise not physically significant. The group speed given by

$$\frac{d\nu}{d(1/\lambda)} = \frac{dE}{dp} = \frac{d}{dp}\left(\frac{p^2}{2m}\right) = \frac{p}{m}$$

is physically meaningful.

CHAPTER 12

12.1 (a) No different from

(b) Thomson

(c) Rutherford

(d) Thomson

(e) Both the models

12.2 The nucleus of a hydrogen atom is a proton. The mass of it is 1.67 $\times$ 10 kg, whereas the mass of an incident α-particle is 6.64 $\times$ 10 kg. Because the scattering particle is more massive than the target nuclei (proton), the α-particle won
in a head-on collision. It is similar to a football colliding with a tenis ball at rest. Thus, there would be no large-angle scattering.

12.3 820 nm.

12.4 5.6×10^{14} Hz

12.5 13.6 eV; eV

12.6 9.7×10^{8} m; 3.1×10^{15} Hz.

12.7 (a) 2.18×10^{6} m/s; 1.09×10^{6} m/s; 7.27×10^{5} m/s

(b) 1.52 $\times$ 10 s; 1.22 $\times$ 10 s; 4.11 $\times$ 10 s.

12.8 2.12$\times$10 m; 4.77 $\times$ 10 m

12.9 Lyman series: 103 nm and 122 nm; Balmer series: 656 nm.

12.10 2.6×10^{74}

12.11 (a) About the same.

(b) Much less.

(c) It suggests that the scattering is predominantly due to a single collision, because the chance of a single collision increases linearly with the number of target atoms, and hence linearly with thickness.

(d) In Thomson
deflection. The observed average scattering angle can be explained only by considering multiple scattering. So it is wrong to ignore multiple scattering in Thomson
Rutherford
single collision and multiple scattering effects can be ignored as a first approximation.

12.12 The first orbit Bohr a_0 given by

$a_0 = \dfrac{4\pi\varepsilon_0 (h/2\pi)^2}{m_e e^2}$. If we consider the atom bound by the gravitational force $(Gm_p m_e / r^2)$, we should replace $(e^2/4\pi\varepsilon_0)$ by $Gm_p m_e$. That is, the radius of the first Bohr orbit is given by $a_0^G = \dfrac{(h/2\pi)^2}{Gm_p m_e^2} \cong 1.2 \times 10^{29}$ m. This is much greater than the estimated size of the whole universe!

12.13 $$\nu = \frac{me^4}{(4\pi)^3 \varepsilon_0^2 (h/2\pi)^3}\left[\frac{1}{(n-1)^2} - \frac{1}{n^2}\right] = \frac{me^4(2n-1)}{(4\pi)^3 \varepsilon_0^2 (h/2\pi)^3 n^2 (n-1)^2}$$

For large n, $\nu \cong \dfrac{me^4}{32\pi^3 \varepsilon_0^2 (h/2\pi)^3 n^3}$

Orbital frequency $\nu_c = (v/2\,\pi\, r)$. In Bohr model $v = \dfrac{n(h/2\pi)}{m\,r}$, and

$r = \dfrac{4\,\pi\,\varepsilon_0 (h/2\pi)^2}{me^2} n^2$. This gives $\nu_c = \dfrac{n(h/2\pi)}{2\,\pi\, mr^2} = \dfrac{me^4}{32\,\pi^3\,\varepsilon_0^2 (h/2\pi)^3 n^3}$

which is same as ν for large n.

12.14 (a) The quantity $\left(\dfrac{e^2}{4\,\pi\,\varepsilon_0 mc^2}\right)$ has the dimensions of length. Its value is 2.82×10 m

(b) The quantity $\dfrac{4\pi\varepsilon_0 (h/2\pi)^2}{me^2}$ has the dimensions of length. Its value is 0.53×10 m

the dimensional arguments cannot, of course, tell us that we should use 4π and $h/2\pi$ in place of h to arrive at the right size.)

12.15 In Bohr $mvr = nh$ and $\dfrac{mv^2}{r} = \dfrac{Ze^2}{4\,\pi\,\varepsilon_0 r^2}$

which give

$$T = \frac{1}{2} mv^2 = \frac{Ze^2}{8\,\pi\,\varepsilon_0 r}\ ;\ r = \frac{4\,\pi\,\varepsilon_0 \hbar^2}{Ze^2 m} n^2$$

These relations have nothing to do with the choice of the zero of potential energy. Now, choosing the zero of potential energy at infinity we have $V = \ \ Ze^2/4\,\pi\,\varepsilon_0\, r)$ which gives $V = \ \ T$ and $E = T + V = \ \ T$

(a) The quoted value of $E =$ eV is based on the customary choice of zero of potential energy at infinity. Using $E = \ \ T$, the kinetic energy of the electron in this state is + 3.4 eV.

(b) Using $V = \ \ T$, potential energy of the electron is =

(c) If the zero of potential energy is chosen differently, kinetic energy does not change. Its value is + 3.4 eV independent of the choice of the zero of potential energy. The potential energy, and the total energy of the state, however, would alter if a different zero of the potential energy is chosen.

12.16 Angular momenta associated with planetary motion are incomparably large relative to h. For example, angular momentum of the earth in its orbital motion is of the order of $10^{70}h$. In terms of the Bohr

value of n (of the order of 10^{70}). For such large values of n, the differences in the successive energies and angular momenta of the quantised levels of the Bohr model are so small compared to the energies and angular momenta respectively for the levels that one can, for all practical purposes, consider the levels continuous.

12.17 All that is needed is to replace m_e by m_μ in the formulas of the Bohr model. We note that keeping other factors fixed, $r \propto (1/m)$ and $E \propto m$. Therefore,

$$r_\mu = \frac{r_e\, m_e}{m_\mu} = \frac{0.53 \times 10}{207} \quad = 2.56 \times 10 \quad \text{m}$$

$$E_\mu = \frac{E_e\, m_\mu}{m_e} = \qquad \cong$$

CHAPTER 13

13.1 (a) 6.941 u (b) 19.9%, 80.1%

13.2 20.18 u

13.3 104.7 MeV

13.4 8.79 MeV, 7.84 MeV

13.5 1.584×10^{25} MeV or 2.535×10^{12} J

13.6 i) ${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$ ii) ${}^{242}_{94}\text{Pu} \rightarrow {}^{238}_{92}\text{U} + {}^{4}_{2}\text{He}$

iii) ${}^{32}_{15}\text{P} \rightarrow {}^{32}_{16}\text{S} + \text{e} \;\; + \bar{\nu}$ iv) ${}^{210}_{83}\text{B} \rightarrow {}^{210}_{84}\text{Po} + \text{e} \;\; + \bar{\nu}$

v) ${}^{11}_{6}\text{C} \rightarrow {}^{11}_{5}\text{B} + \text{e}^{+} + \nu$ vi) ${}^{97}_{43}\text{Tc} \rightarrow {}^{97}_{42}\text{Mo} + \text{e}^{+} + \nu$

vii) ${}^{120}_{54}\text{Xe} + \text{e}^{+} \rightarrow {}^{120}_{53}\text{I} + \nu$

13.7 (a) 5 T years (b) 6.65 T years

13.8 4224 years

13.9 $7.126 \times 10^{\;6}$ g

13.10 7.877×10^{10} Bq or 2.13 Ci

13.11 1.23

13.12 (a) Q = 4.93 MeV, E_{α} = 4.85 MeV (b) Q = 6.41 MeV, E_{α} = 6.29 MeV

13.13 ${}^{11}_{6}\text{C} \rightarrow {}^{11}_{6}\text{B} + \text{e}^{+} + \nu \; + Q$

$$Q = \left[m_N\left({}^{11}_{6}\text{C}\right) \quad m_N\left({}^{11}_{6} \quad\right) \quad m_e\right]c^2 ,$$

where the masses used are those of nuclei and not of atoms. If we use atomic masses, we have to add $6m_e$ in case of ^{11}C and $5m_e$ in case of ^{11}B. Hence

$$Q = \left[m\left({}^{11}_{6}\text{C}\right) \quad m\left({}^{11}_{6} \quad\right) \quad m_e\right]c^2 \quad \text{(Note } m_e \text{ has been doubled)}$$

Using given masses, Q = 0.961 MeV.

$Q = E_d + E_e + E_{\nu}$

The daughter nucleus is too heavy compared to e^{+} and ν, so it carries negligible energy ($E_d \approx 0$). If the kinetic energy (E_{ν}) carried by the neutrino is minimum (i.e., zero), the positron carries maximum energy, and this is practically all energy Q; hence maximum $E_e \approx Q$).

13.14 ${}^{23}_{10}\text{Ne} \rightarrow {}^{23}_{11}\text{Na} + \text{e} \;\; + \bar{\nu} + Q$; $Q = \left[m_N\left({}^{23}_{10}\text{Ne}\right) \quad m_N\left({}^{23}_{11} \quad\right) \quad m_e\right]c^2$, where the masses used are masses of nuclei and not of atoms as in Exercise 13.13. Using atomic masses $Q = \left[m\left({}^{23}_{10}\text{Ne}\right) \quad m\left({}^{23}_{11} \quad\right)\right]c^2$. Note m_e has been cancelled. Using given masses, Q = 4.37 MeV. As in Exercise 13.13, maximum kinetic energy of the electron (max E_e) = Q = 4.37 MeV.

13.15 (i) Q = 4.03 MeV; endothermic

(ii) Q = 4.62 MeV; exothermic

13.16 $Q = \quad m\left({}^{56}_{26}\text{Fe}\right) \quad m\left({}^{28}_{13} \quad\right)$ = 26.90 MeV; not possible.

13.17 4.536×10^{26} MeV

13.18 Energy generated per gram of ${}^{235}_{92}\text{U}$ = $\dfrac{6 \times 10^{23} \times 200 \times 1.6 \times 10^{-13}}{235}$ J g^{-1}

The amount of $^{235}_{92}\text{U}$ consumed in 5y with 80% on-time

$$= \frac{5 \times 0.8 \times 3.154 \times 10^{16} \times 235}{1.2 \times 1.6 \times 10^{13}} \text{ g} \qquad = 1544 \text{ kg}$$

The initial amount of $^{235}_{92}\text{U}$ = 3088 kg.

13.19 About 4.9 x 10^4 y

13.20 360 KeV

13.22 Consider the competing processes:

$^{A}_{Z}\text{X} \rightarrow ^{A}_{Z}\ \text{Y} + e^{+} + \nu_e + Q$ (positron capture)

$e \ + ^{A}_{Z}\text{X} \rightarrow ^{A}_{Z}\ \text{Y} + \nu_e + Q$ (electron capture)

$$Q_1 = \left[m_N\left(^{A}_{Z}\text{X}\right) \quad m_N\left(^{A}_{Z} \quad \right) \quad m_e\right]c^2$$

$$= \left[m_N\left(^{A}_{Z}\text{X}\right) \quad Z m_e \quad m\left(^{A}_{Z} \quad \right) \quad (Z \quad)m_e \quad m_e\right]c^2$$

$$= \left[m\left(^{A}_{Z}\text{X}\right) \quad m\left(^{A}_{Z} \quad \right) \quad m_e\right]c^2$$

$$Q_2 = \left[m_N\left(^{A}_{Z}\text{X}\right) + m_e \quad m_N\left(^{A}_{Z} \quad \right)\right]c^2 = \left[m\left(^{A}_{Z}\text{X}\right) \quad m\left(^{A}_{Z} \quad \right)\right]c^2$$

This means $Q_1 > 0$ implies $Q_2 > 0$ but $Q_2 > 0$ does not necessarily mean $Q_1 > 0$. Hence the result.

13.23 $^{25}_{12}\text{Mg}$: 9.3%, $^{26}_{12}\text{Mg}$:11.7%

13.24 Neutron separation energy S_n of a nucleus $^{A}_{Z}\text{X}$ is

$$S_n = \left[m_N(^{A-1}_{Z}\text{X}) + m_n - m_N(^{A}_{Z}\text{X})\right]c^2$$

From given data , $S_n(^{41}_{20}\text{Ca}) = 8.36\text{MeV}, S_n(^{27}_{13}\text{Al}) = 13.06\text{MeV}$

13.25 209 d

13.26 For $^{14}_{6}\text{C}$ emission

$$Q = [m_N(^{223}_{88}\text{Ra}) - m_N(^{209}_{82}\text{Pb}) - m_N(^{14}_{6}\text{C})]c^2$$

$$= [m(^{223}_{88}\text{Ra}) - m(^{209}_{82}\text{Pb}) - m(^{14}_{6}\text{C})]c^2 = 31.85 \text{ MeV}$$

For $^{4}_{2}\text{He}$ emission, $Q = [m(^{223}_{88}\text{Ra}) - m(^{219}_{86}\text{Rn}) - m(^{4}_{2}\text{He})]c^2 = 5.98 \text{MeV}$

13.27 $Q = [m(^{238}_{92}\text{U}) + m_n - m(^{140}_{58}\text{Ce}) - m(^{99}_{44}\text{Ru})]c^2 = 231.1$ MeV

13.28 (a) $Q = [m(^{2}_{1}\text{H}) + m(^{3}_{1}\text{H}) - m(^{4}_{2}\text{He}) - m_n]c^2 = 17.59$ MeV

(b) K.E. required to overcome Coulomb repulsion = 480.0 keV

480.0 KeV = 7.68x 10 J = 3kT

$$\therefore T = \frac{7.68 \times 10}{3 \times 1.381 \times 10} \qquad (\text{as } k = 1.381 \times 10 \quad \text{J K} \quad)$$

= 1.85 x 10^9 K (required temperature)

13.29 $K_{max}\left(\beta_1\right) = 0.284$ MeV, $K_{max}\left(\beta_2\right) = 0.960$ MeV

$\nu\left(\gamma_1\right) = 2.627 \times 10^{20}$ Hz , $\nu\left(\gamma_2\right) = 0.995 \times 10^{20}$ Hz , $\nu\left(\gamma_3\right) = 1.632 \times 10^{20}$ Hz

13.30 (a) Note that in the interior of Sun, four ${}_1^1H$ nuclei combine to form one ${}_2^4He$ nucleus releasing about 26 MeV of energy per event.

Energy released in fusion of 1kg of hydrogen = 39 $\times$ 10^{26} MeV

(b) Energy released in fission of 1kg of ${}_{92}^{235}U$ = 5.1 $\times$ 10^{26} MeV

The energy released in fusion of 1 kg of hydrogen is about 8 times that of the energy released in the fusion of 1 kg of uranium.

13.31 3.076 $\times$ 10^4 kg

Chapter 14

14.1 (c)

14.2 (d)

14.3 (c)

14.4 (c)

14.5 (c)

14.6 (b), (c)

14.7 (c)

14.8 50 Hz for half-wave, 100 Hz for full-wave

14.9 v_i = 0.01 V ; I_B = 10 μA

14.10 2V

14.11 No ($h\nu$ has to be greater than E_g).

14.12 $n_e \approx 4.95 \times 10^{22}$; $n_h = 4.75 \times 10^9$; n-type since $n_e >> n_h$

For charge neutrality $N_D \quad {}_A = n_e \quad {}_h$; $n_e.n_h = n_i^2$

Solving these equations, $n_e = \frac{1}{2}\left[(N_D - N_A) + \sqrt{(N_D - N_A)^2 + 4n_i^2}\right]$

14.13 About 1 $\times$ 10^5

14.14 (a) 0.0629 A, (b) 2.97 A, (c) 0.336 Ω

(d) For both the voltages, the current I will be almost equal to I_0, showing almost infinite dynamic resistance in the reverse bias.

14.16 NOT ;

A	Y
0	1
1	0

14.17 (a) AND (b) OR

14.18 OR gate

14.19 (a) NOT, (b) AND

Chapter 15

15.1 (b) 10 kHz cannot be radiated (antenna size), 1GHz and 1000 GHz will penetrate.

15.2 (d) Consult Table 15.2

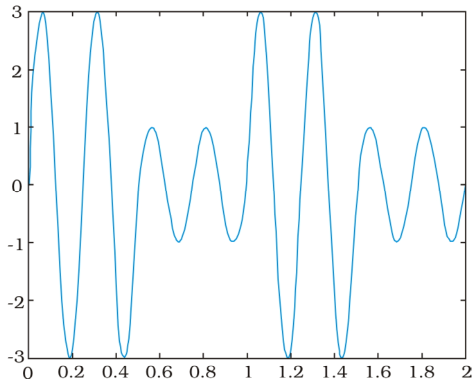
15.3 (c) Decimal system implies continuous set of values

15.4 No. Service area will be $A = \pi d_T^2 = \frac{22}{7} \times 162 \times 6.4 \times 10^6 = 3258\ \text{km}^2$.

15.5 $\mu = 0.75 = \frac{A_m}{A_c}$

$A_m = 0.75 \times 12 = 9\ \text{V}$.

15.6 (a)



(b) $\mu = 0.5$

15.7 Since the AM wave is given by $(A_c + A_m \sin\omega_m t) \cos \omega_c t$, the maximum amplitude is $M_1 = A_c + A_m$ while the minimum amplitude is $M_2 = A_c \quad A_m$. Hence the modulation index is

$$m = \frac{A_m}{A_c} = \frac{M_1 \quad M_2}{M_1 + M_2} = \frac{8}{12} = \frac{2}{3}.$$

With $M_2 = 0$, clearly, $m = 1$, irrespective of M_1.

15.8 Let, for simplicity, the received signal be
$A_1 \cos(\omega_c + \omega_m)t$
The carrier $A_c \cos \omega_c t$ is available at the receiving station. By multiplying the two signals, we get
$A_1 A_c \cos(\omega_c + \omega_a)t \cos \omega_c t$

$$= = \frac{A_1 A_c}{2}\left[\cos(2\omega_c + \omega_m)t + \cos \omega_m t\right]$$

If this signal is passed through a low-pass filter, we can record the modulating signal $\frac{A_1 A_c}{2} \cos \omega_m t$.

BIBLIOGRAPHY

TEXTBOOKS

For additional reading on the topics covered in this book, you may like to consult one or more of the following books. Some of these books however are more advanced and contain many more topics than this book.

1 Ordinary Level Physics, A.F. Abbott, Arnold-Heinemann (1984).
2 Advanced Level Physics, M. Nelkon and P. Parker, 6th Edition, Arnold-Heinemann (1987).
3 Advanced Physics, Tom Duncan, John Murray (2000).
4 Fundamentals of Physics, David Halliday, Robert Resnick and Jearl Walker, 7th Edition John Wily (2004).
5 University Physics (Sears and Zemansky th Edition, Addison
6 Problems in Elementary Physics, B. Bukhovtsa, V. Krivchenkov, G. Myakishev and V. Shalnov, MIR Publishers, (1971).
7 Lectures on Physics (3 volumes), R.P. Feynman, Addision
8 Berkeley Physics Course (5 volumes) McGraw Hill (1965).
   a. Vol. 1
   b. Vol. 2
   c. Vol. 3
   d. Vol. 4
   e. Vol. 5 f)
9 Fundamental University Physics, M. Alonso and E. J. Finn, Addison
10 College Physics, R.L. Weber, K.V. Manning, M.W. White and G.A. Weygand, Tata McGraw Hill (1977).
11 Physics: Foundations and Frontiers, G. Gamow and J.M. Cleveland, Tata McGraw Hill (1978).
12 Physics for the Inquiring Mind, E.M. Rogers, Princeton University Press (1960).
13 PSSC Physics Course, DC Heath and Co. (1965) Indian Edition, NCERT (1967).
14 Physics Advanced Level, Jim Breithampt, Stanley Thornes Publishers (2000).
15 Physics, Patrick Fullick, Heinemann (2000).
16 Conceptual Physics, Paul G. Hewitt, Addision
17 College Physics, Raymond A. Serway and Jerry S. Faughn, Harcourt Brace and Co. (1999).
18 University Physics, Harris Benson, John Wiley (1996).
19 University Physics, William P. Crummet and Arthur B. Western, Wm.C. Brown (1994).
20 General Physics, Morton M. Sternheim and Joseph W. Kane, John Wiley (1988).
21 Physics, Hans C. Ohanian, W.W. Norton (1989).

22 Advanced Physics, Keith Gibbs, Cambridge University Press (1996).
23 Understanding Basic Mechanics, F. Reif, John Wiley (1995).
24 College Physics, Jerry D. Wilson and Anthony J. Buffa, Prentice Hall (1997).
25 Senior Physics, Part I.K. Kikoin and A.K. Kikoin, MIR Publishers (1987).
26 Senior Physics, Part B. Bekhovtsev, MIR Publishers (1988).
27 Understanding Physics, K. Cummings, Patrick J. Cooney, Priscilla W. Laws and Edward F. Redish, John Wiley (2005).
28 Essentials of Physics, John D. Cutnell and Kenneth W. Johnson, John Wiley (2005).

GENERAL BOOKS

For instructive and entertaining general reading on science, you may like to read some of the following books. Remember however, that many of these books are written at a level far beyond the level of the present book.

1 Mr. Tompkins in paperback, G. Gamow, Cambridge University Press (1967).
2 The Universe and Dr. Einstein, C. Barnett, Time Inc. New York (1962).
3 Thirty years that Shook Physics, G. Gamow, Double Day, New York (1966).
4 Surely You , R.P. Feynman, Bantam books (1986).
5 One, Two, Three , G. Gamow, Viking Inc. (1961).
6 The Meaning of Relativity, A. Einstein, (Indian Edition) Oxford and IBH Pub. Co. (1965).
7 Atomic Theory and the Description of Nature, Niels Bohr, Cambridge (1934).
8 The Physical Principles of Quantum Theory, W. Heisenberg, University of Chicago Press (1930).
9 The Physics , F. Hoyle and J.V. Narlikar, W.H. Freeman (1980).
10 The Flying Circus of Physics with Answer, J. Walker, John Wiley and Sons (1977).
11 Physics for Everyone (series), L.D. Landau and A.I. Kitaigorodski, MIR Publisher (1978).
Book 1: Physical Bodies
Book 2: Molecules
Book 3: Electrons
Book 4: Photons and Nuclei.
12 Physics can be Fun, Y. Perelman, MIR Publishers (1986).
13 Power of Ten, Philip Morrison and Eames, W.H. Freeman (1985).
14 Physics in your Kitchen Lab., I.K. Kikoin, MIR Publishers (1985).
15 How Things Work: The Physics of Everyday Life, Louis A. Bloomfield, John Wiley (2005).
16 Physics Matters: An Introduction to Conceptual Physics, James Trefil and Robert M. Hazen, John Wiley (2004).

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