PHYSICS OF REMOTE SENSING

B. L. DEEKSHATULU AND O. P. BAJPAI
National Remote Sensing Agency, No. 4, Sardar Patel Road, Secunderabad 500 003,
India.

INTRODUCTION

REMOTE Sensing is the Science of deriving information about an object from measurements made at a distance from the object without actually coming in contact with it. Sensors and techniques used have improved our capability to gather information about the earth's natural resources and environment. It can be either an active system or a passive system. In both the cases, it depends on reflected/emitted Electro-Magnetic (EM) energy from the ground targets. Electro-magnetic (EM) spectrum extends from energetic gamma rays to micro-waves, radio-waves through x-rays, ultra-violet, visible and infra-red regions. The different portions of the spectrum are different only in their wave-lengths and all of them travel with the same velocity in vacuum known as the velocity of light, $C = 3 \times 10^{10}$ cm/sec. Remote sensing—a technique for making measurements on a object at a distance—to a great extent relies on the interaction of E.M. radiation with matter. Figure 1 shows the energy exchange in the natural environment. Macroscopically, the interactions are absorption, transmission, reflection and emission of radiation from the features. Microscopically, these are due to atomic, molecular absorption and scattering. These physical processes affect, say, the reflected/emitted radiation (signal) measured by remote sensors. The remotely sensed signal measured as a function of a wave-length is often referred to as the "Spectral Signature" of the target/object on which measurements have been made. In principle, Spectral Signatures are unique. That is, different objects have different spectral signatures under different conditions. It would therefore be possible to identify the object from its spectral signature. This is in brief, the principle of multispectral remote sensing which is a powerful technique for monitoring of natural resources/environment. To utilise remote sensing techniques effectively, it is necessary to understand the underlying physical process. Generally, it is very complicated and hence the macroscopic effects are discussed from phenomenological viewpoint. This report begins with giving illustrations of the typical spectral signatures of earth features and effects of physical, biological processes on the spectral signatures followed by a brief discussion on the effects of atmosphere on remote sensing and possible ways of correcting for them. The instrumentation for multispectral remote sensing are also discussed followed by a brief mention of the applications of remote sensing to various disciplines. The discussion will be limited to the optical region of the E.M. spectrum *i.e.* 0.3 to 15 μm which is the most exploited spectral region for remote sensing.

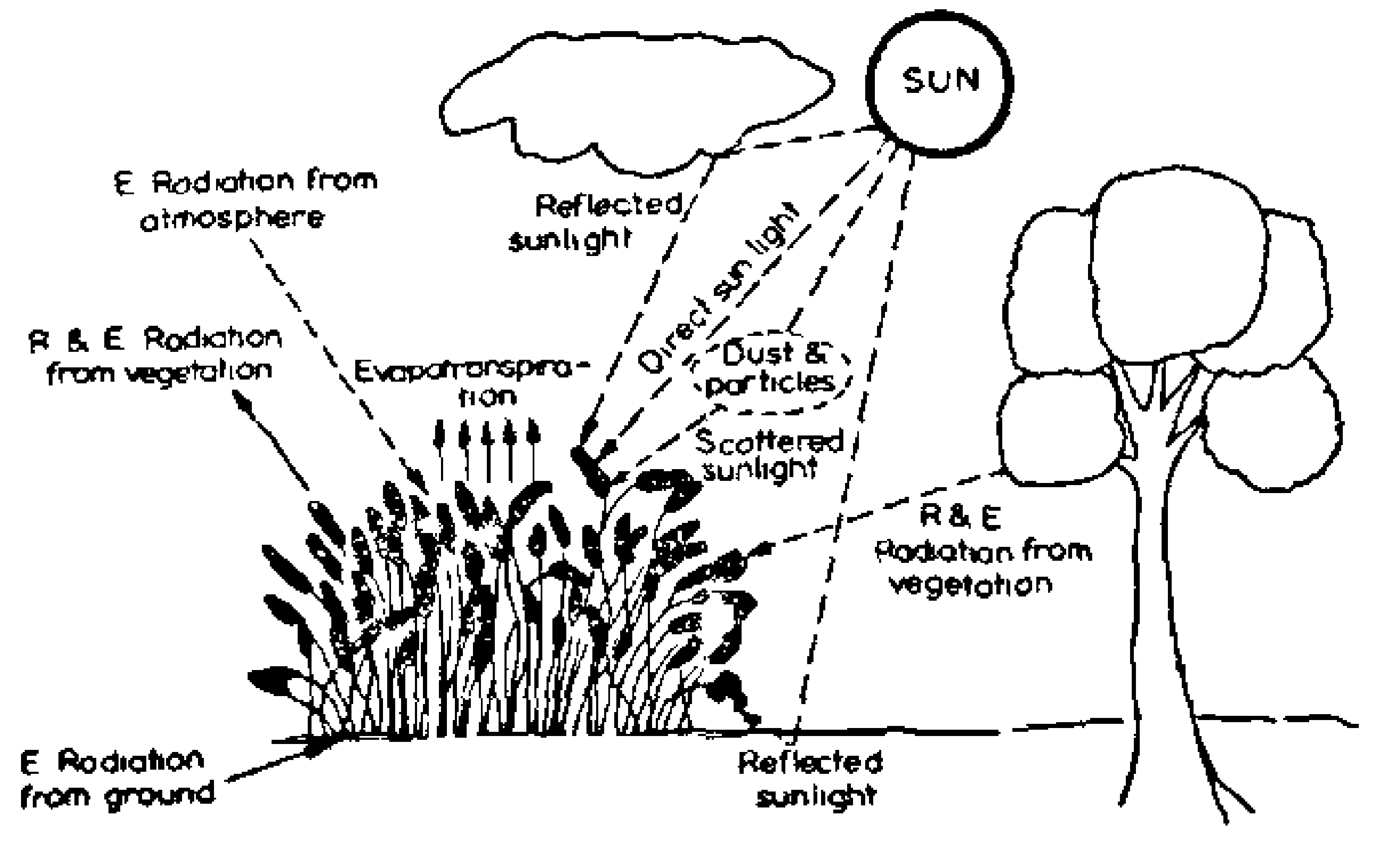

Figure 1. Energy exchange in the natural environment R = Reflected, E = Emitted.

SPECTRAL SIGNATURES OF EARTH SURFACES FEATURES:

(i) *Spectral, Temporal and Spatial characteristics of the scene:*

Manual photointerpretation as well as the machine aided identification of man-made object rely on spatial features of the object like size, shape and texture or linear features. However, the identification of objects like crop, water, soils etc. is carried out using their different spectral characteristics. Both the spatial and spectral characteristics of the objects change with time. Temporal changes in spectral response can be either natural, such as the seasonal changes in tree foliage, or they can be caused by human beings, such as caused by the farmers who plough under the stubble in their fields or cause construction work by removing surface vegetation and expose the soil below. In remote sensing "change detection" techniques can be used to monitor these temporal changes.

(a) Spectral characteristics of vegetation:

Figure 2 shows the typical spectral curve for green vegetation: In the visible wavelength, pigmentation dominates spectral response of plants and chlorophyll is especially important. In Near Infrared, reflectance rises noticeably because the green leaf absorbs very little energy in this region. In MIR, water absorbs energy strongly in particular wavelengths. Green leaves have very high moisture content, therefore water absorption band dominates the spectral response in this region. The inter-relationship as a function of wavelength are shown by energy balance equation

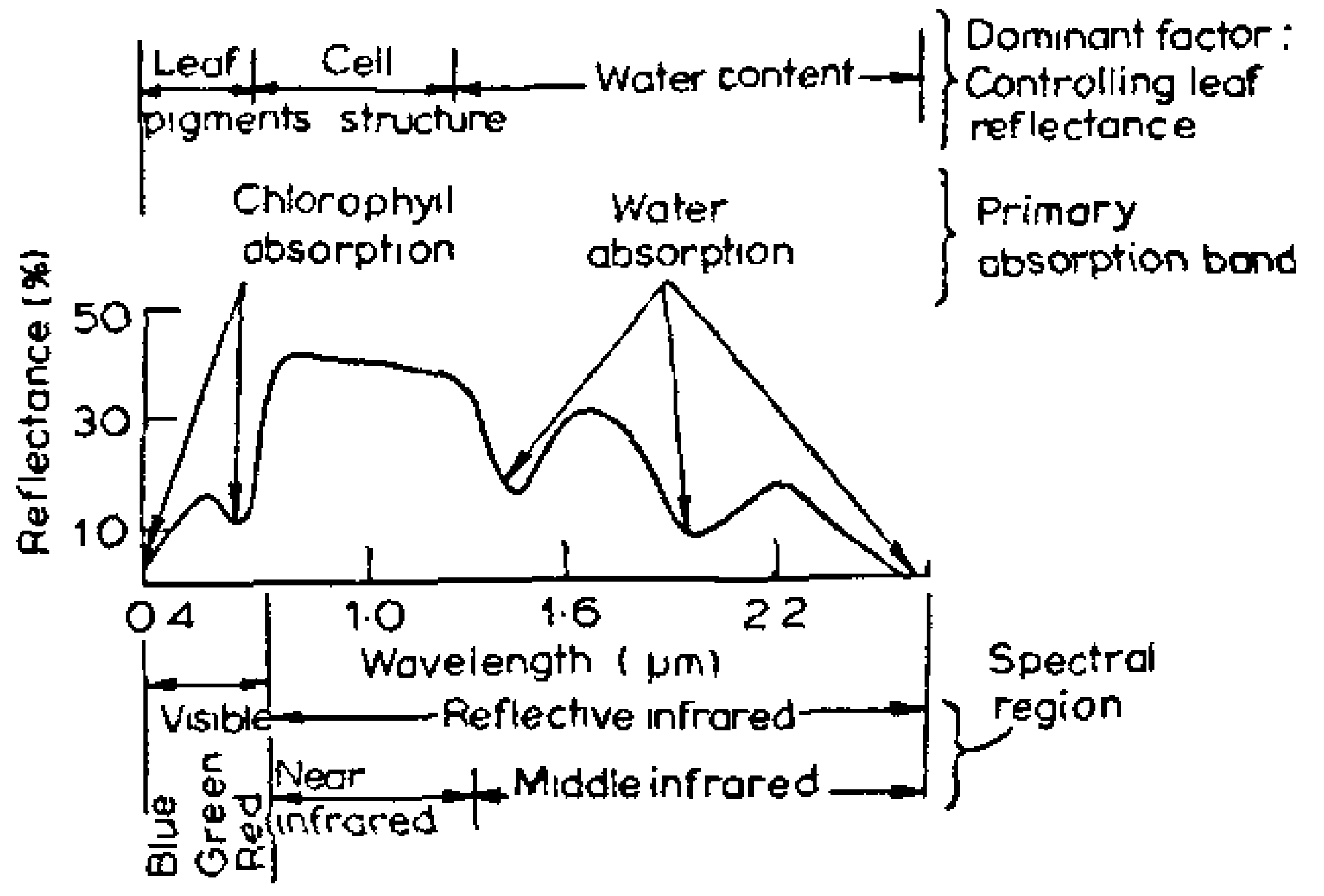

Figure 2. Significant spectral response characteristics of green vegetation.

$$I_\lambda = R_\lambda + A_\lambda + T_\lambda \qquad (1)$$

where I_λ = Incident energy R_λ = Reflected energy A_λ = absorbed energy T_λ = Transmitted energy

Most of the remote sensing instruments operate in 0.3 to 3.0 μm portion, where reflected energy is more useful.

$$R_\lambda = I_\lambda - (A_\lambda + T_\lambda) \qquad (2)$$

In the visible wavelengths most of the energy striking a green leaf is absorbed and very little is transmitted through leaf. Figure 2 shows a reflective peak at approximately 0.54 μm, which is green wavelength region. The effect of difference in pigmentation on leaf spectra are shown in figure 3. We see significant difference in reflectance in the visible region due to difference in pigmentation of the leaves, but there is no significant differences in reflectance in the NIR or MIR portion of spectrum. In the NIR healthy green vegetation is characterized by very high reflectance, very high transmittance and very low absorption as compared to visible wavelengths. Figure 4 shows an example of the effect of multiple leaf layers on vegetative reflectance. I is the incoming energy, T = Transmitted energy and R is the reflected energy. Figure 5 shows the reflectance from the combination of leaves stacked one on another upto six deep.

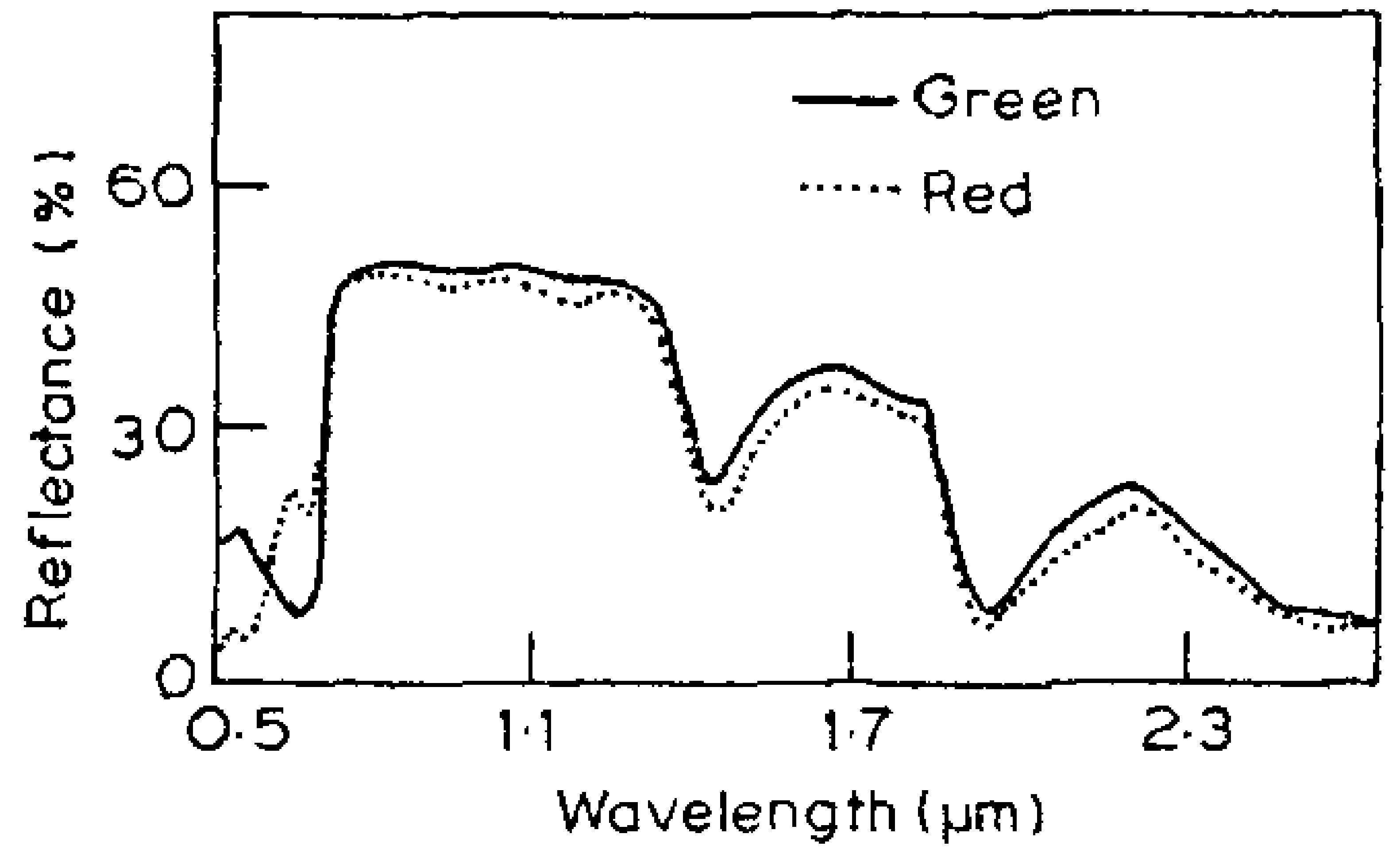

Figure 3. The effect of pigmentation on leaf reflectance.

In the middle IR portion of the spectrum, the spectral response of green vegetation is dominated by strong water absorption bands which occur near 1.4, 1.9 and 2.7 μm. The absorption

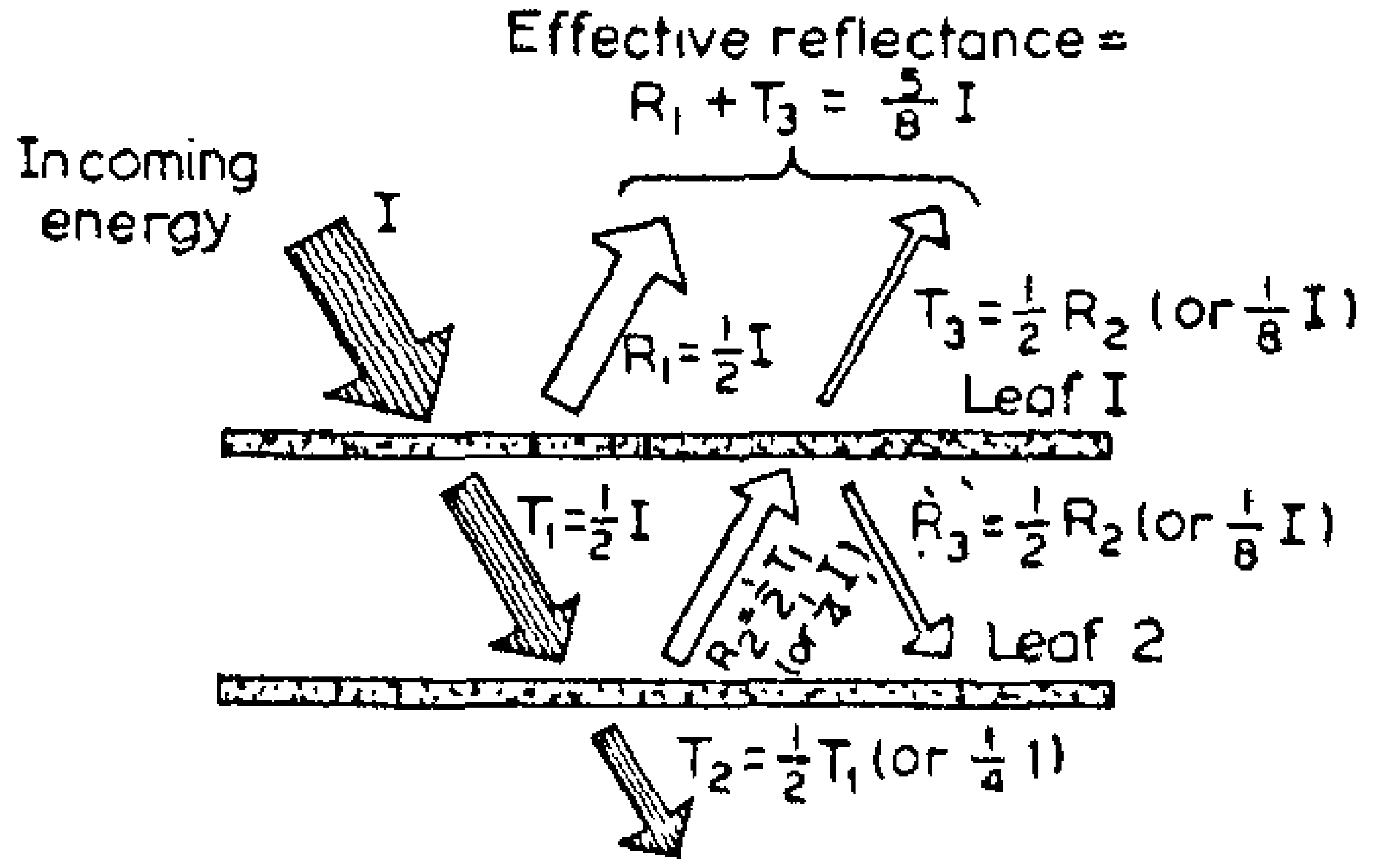

Figure 4. Simplified sketch of the effect of multiple—leaf layers on vegetative reflectance. I = Incoming energy; T = transmitted energy; R = reflected energy.

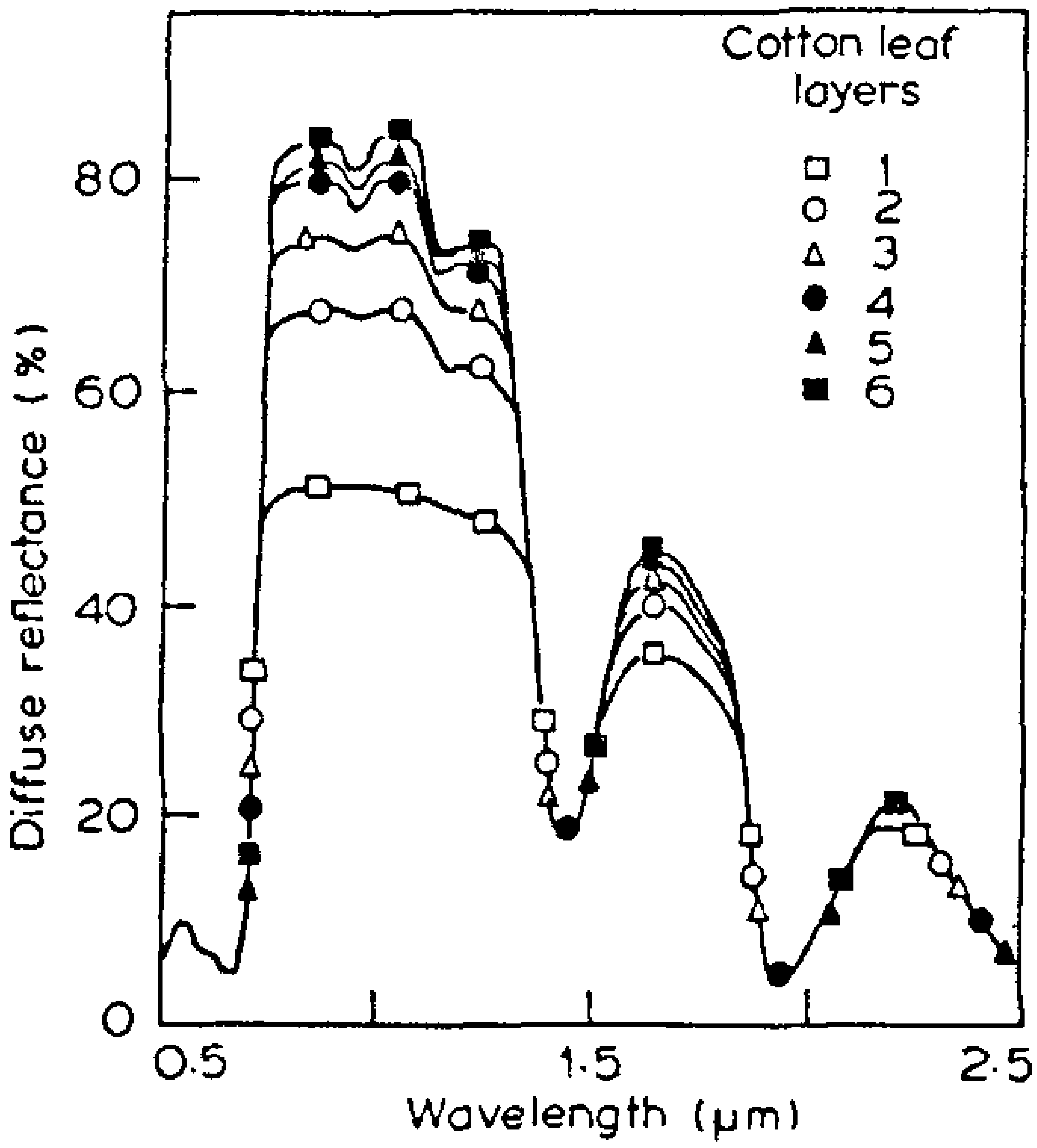

Figure 5. Reflectance from combinations of cotton leaves stacked on one another, up to six deep.

band at 2.7 µm is a major one and is referred to as a fundamental vibrational water absorption band. Similar absorption band occurs at 6.27 µm. Figure 6 shows that leaf reflectance in the MIR. The effect of moisture content on leaf reflectance is shown in figure 7: At very low level of moisture content, the plants were dying or dead, the leaves had lost most of their chlorophyll and the increase in reflectance was substantial throughout the reflective region of the spectrum. As leaves lose moisture drastic changes which occur in their internal structure affect the NIR.

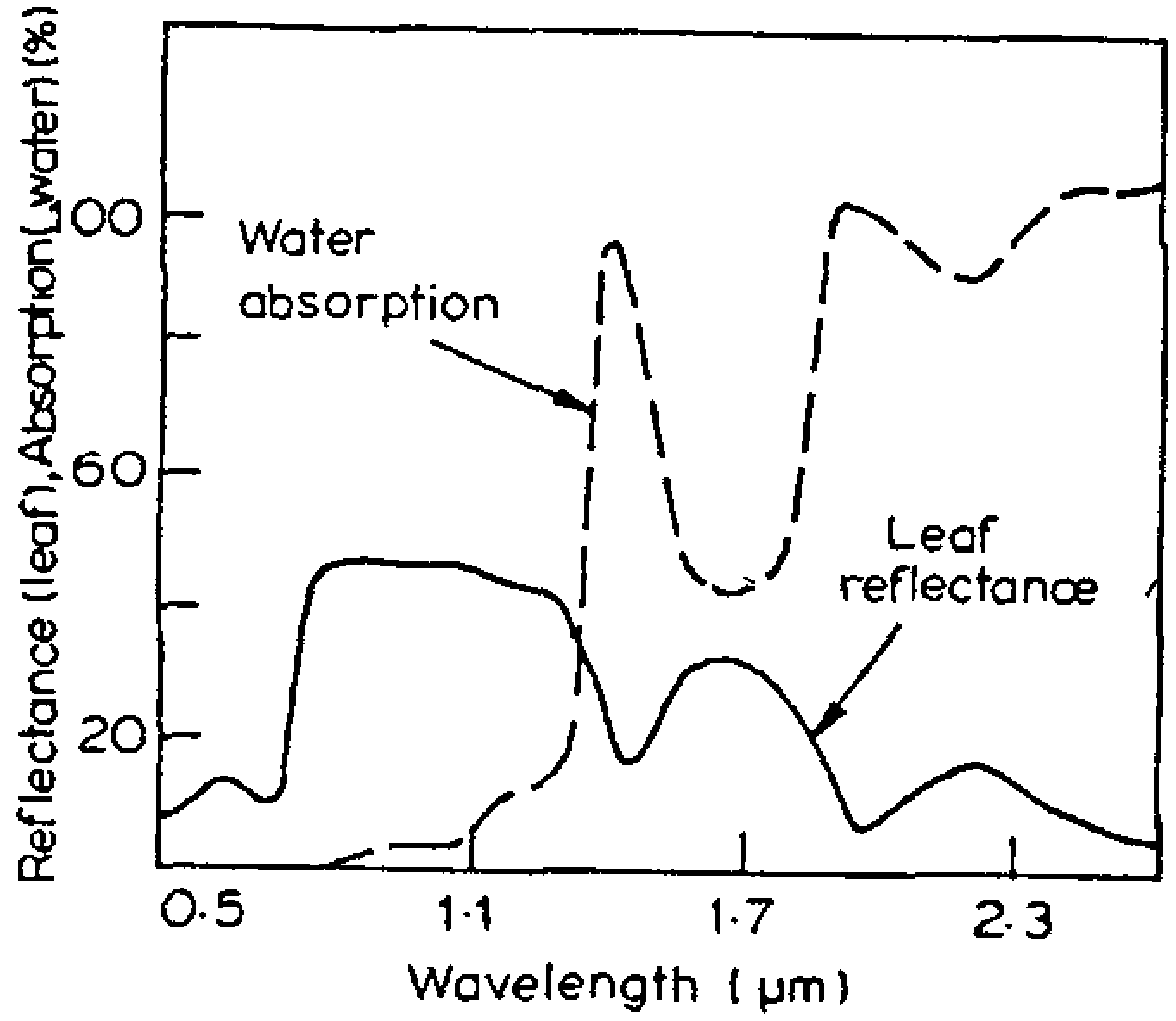

Figure 6. The inverse relationship between leaf reflectance and water absorption. The water absorption curve represents the amount of absorption caused by a layer of water 1 mm deep.

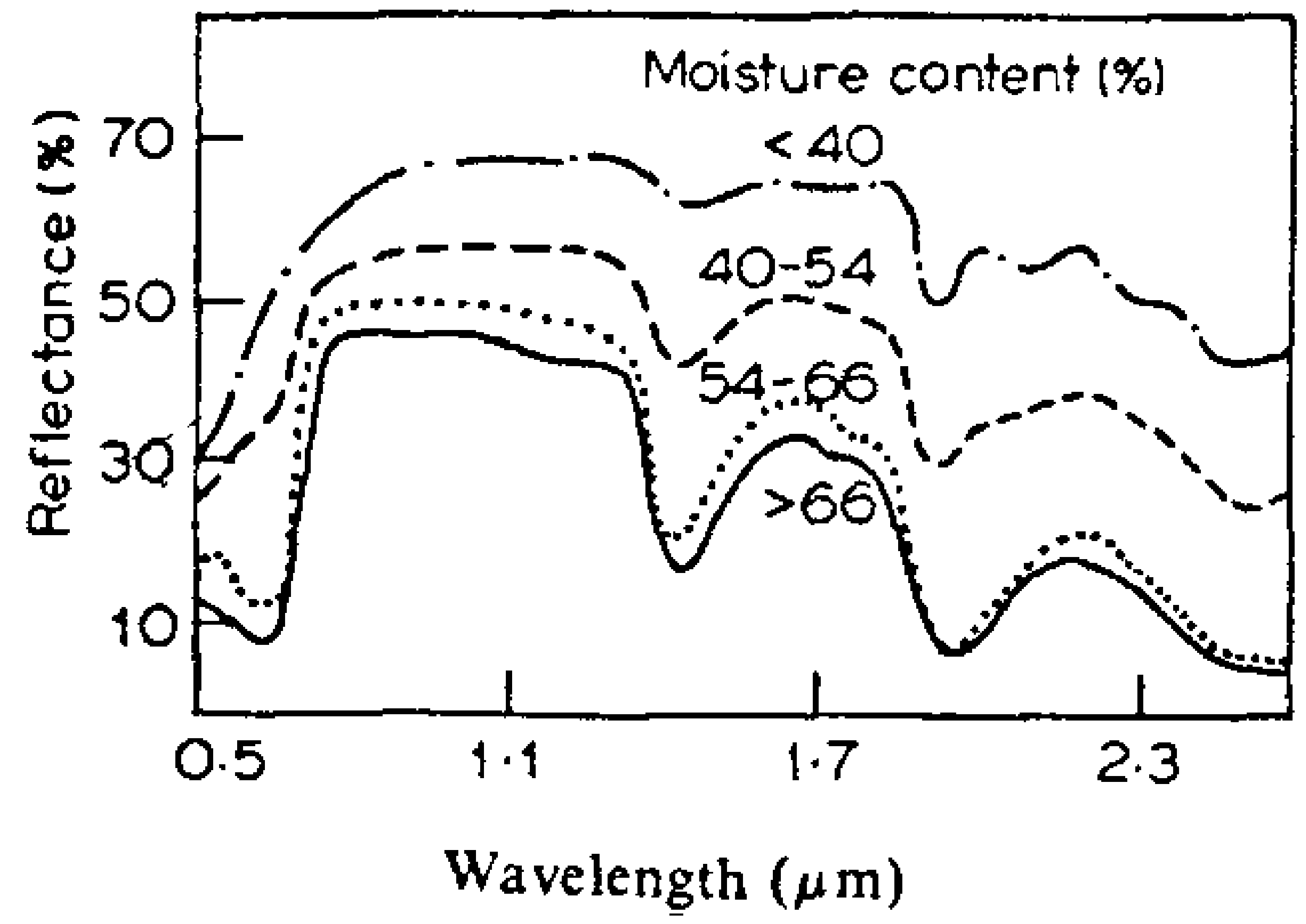

Figure 7. Effect of moisture content on reflectance of corn leaves.

(*b*) *Spectral characteristics of soil*:

Spectral reflectance curves from most of the soil materials are generally less complex in appearance than those from vegetation. The moisture content, the amount of organic matter, the amount of iron oxide, the relative percentages of clay, silt and sand, particle size and the roughness characteristics of the soil surface, all significantly influence the spectral reflectance of soils. An increase in iron oxide can cause a significant decrease in reflectance, atleast in the visible wavelengths. A soil that exhibits no reversal between the reflective and thermal portion of the spectrum, is a relatively moist soil whereas an area that is light, in reflective as well as the thermal portions of the spectrum is indicative of a relatively light coloured, dry soil. Finally an area that is relatively dark in the reflective region and light in the thermal region indicates a relatively dry soil, perhaps having a high organic matter content. In soils usually, the amplitude difference of reflectance among various soils and soil conditions is consistent throughout the various wavelength regions

Figures 8–11 show the various characteristics of soils in various conditions as mentioned above.

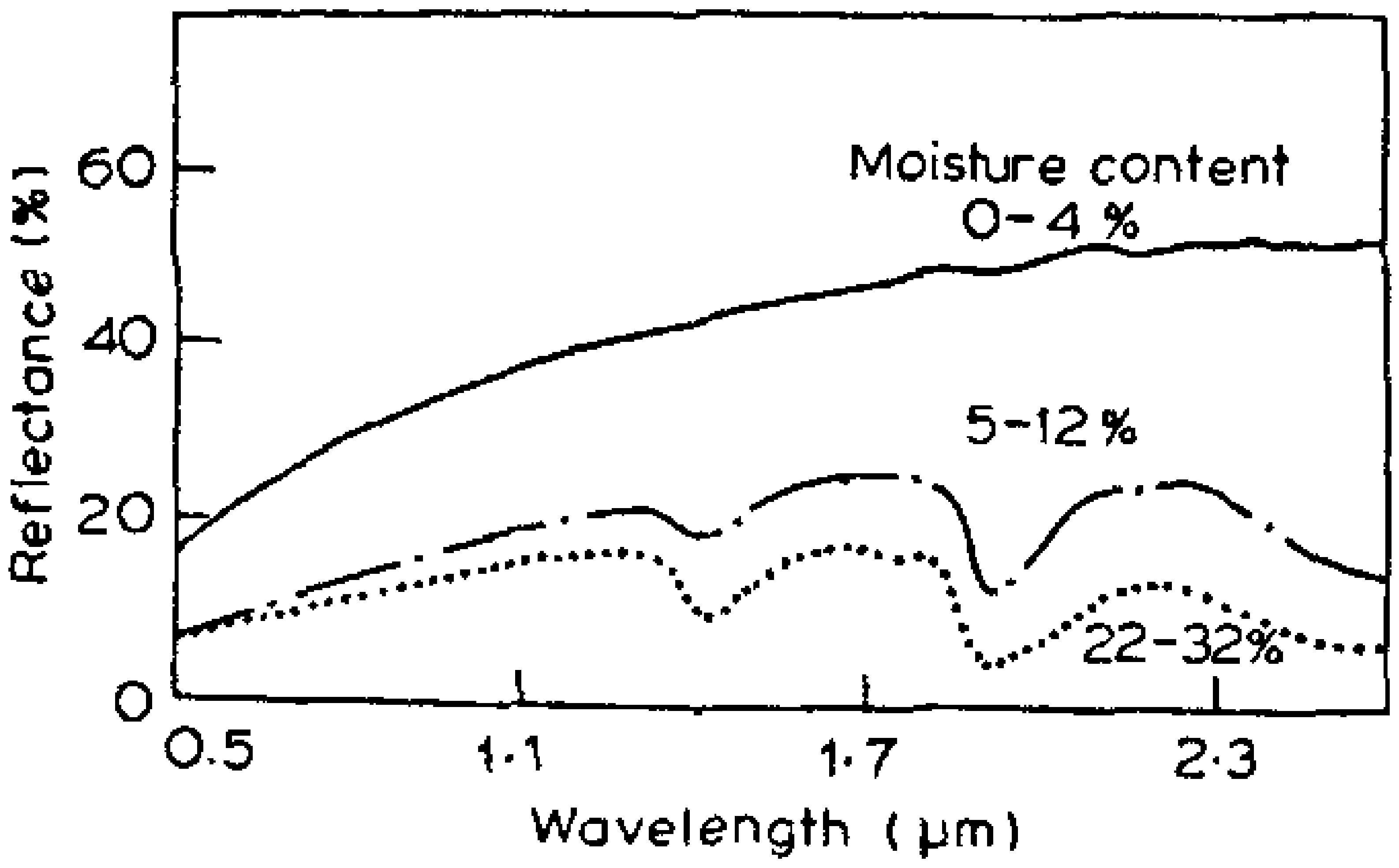

Figure 8. Special reflectance curves for chelsea sand in three moisture content groupings.

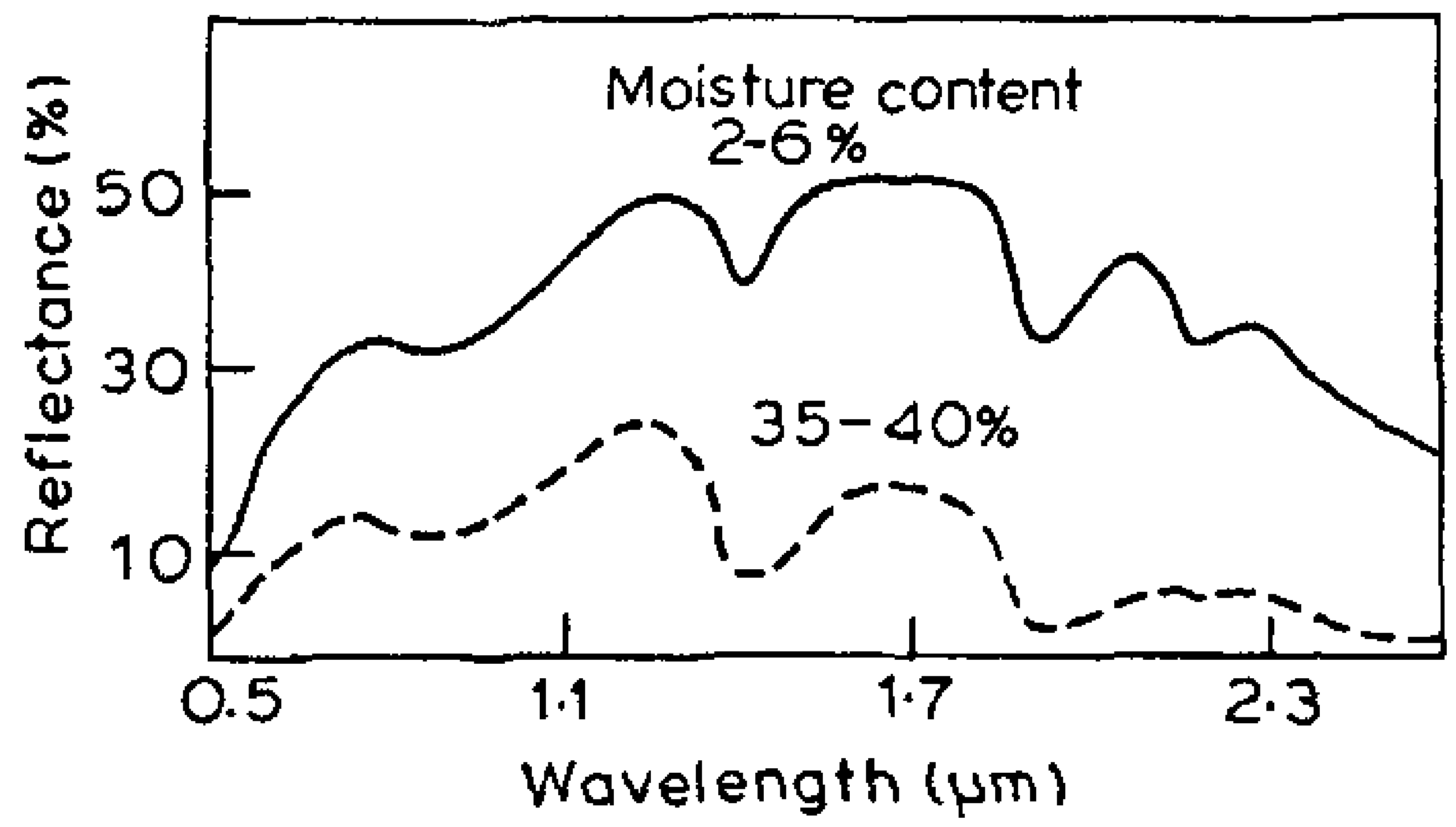

Figure 9. Spectral reflectance curves for a typical clay soil (pembroke) at two moisture contents.

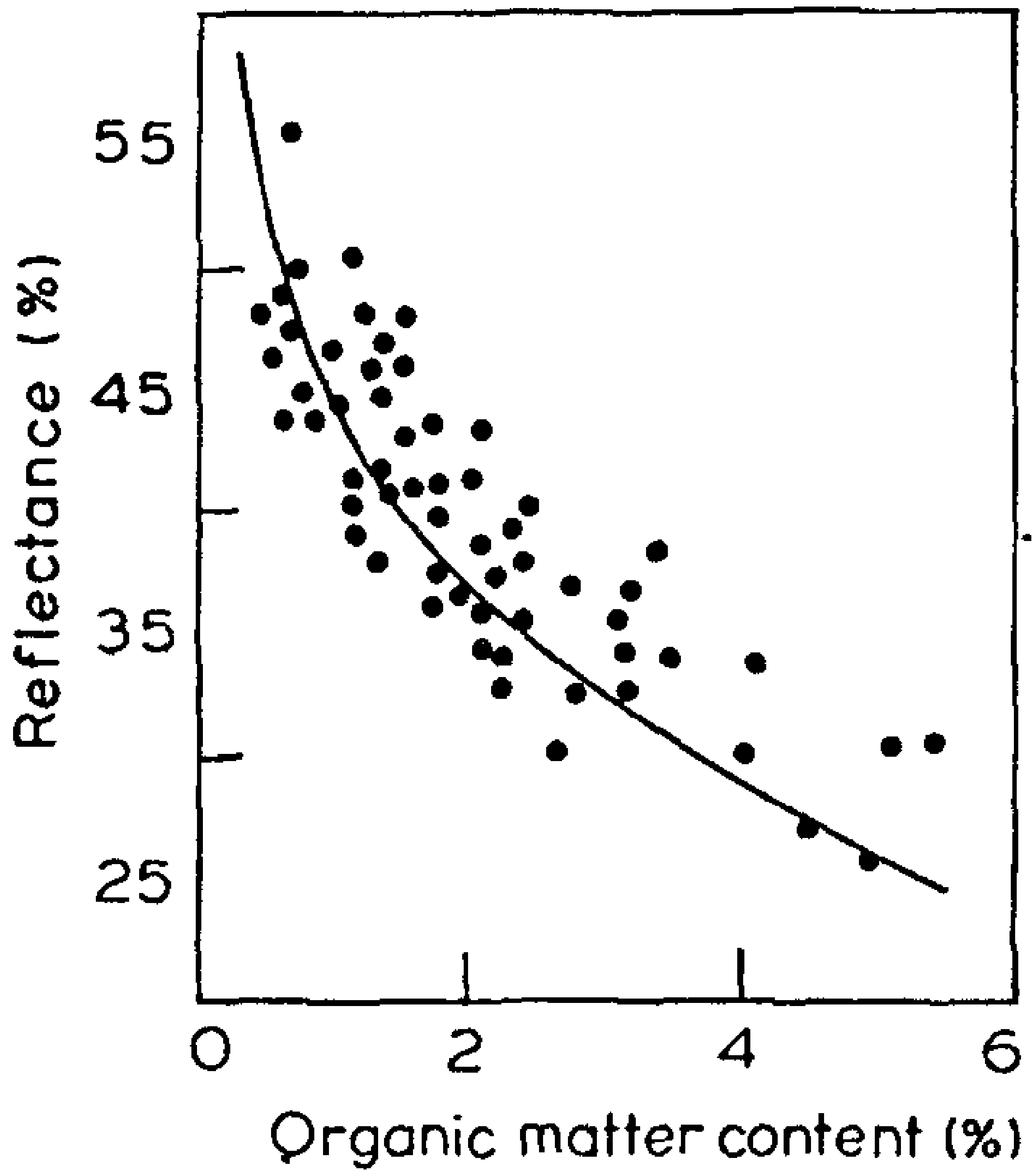

Figure 10. Relationship between organic matter content and reflectance.

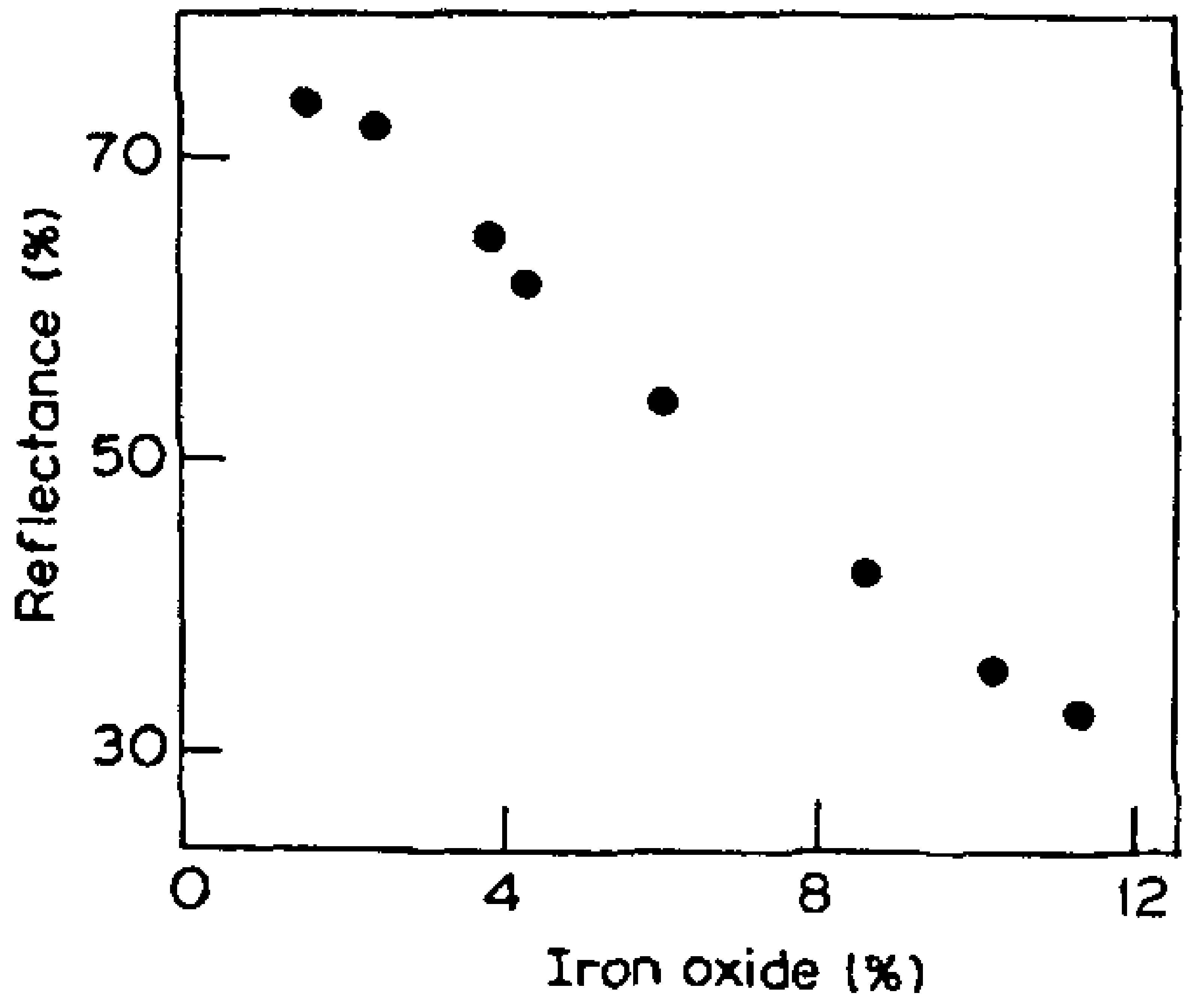

Figure 11. Relationship between ironoxide and soil reflectance in the 0.50-64 μm wavelength band.

(*c*) *Spectral characteristics of water and snow*:

As with vegetation and soil, the spectral response of water varies with the wavelength. For water bodies, the interactions are a result of the water itself and are further affected by various conditions of water. Locating and delineating water bodies by remote sensing can be done most easily in the Near IR wavelength while

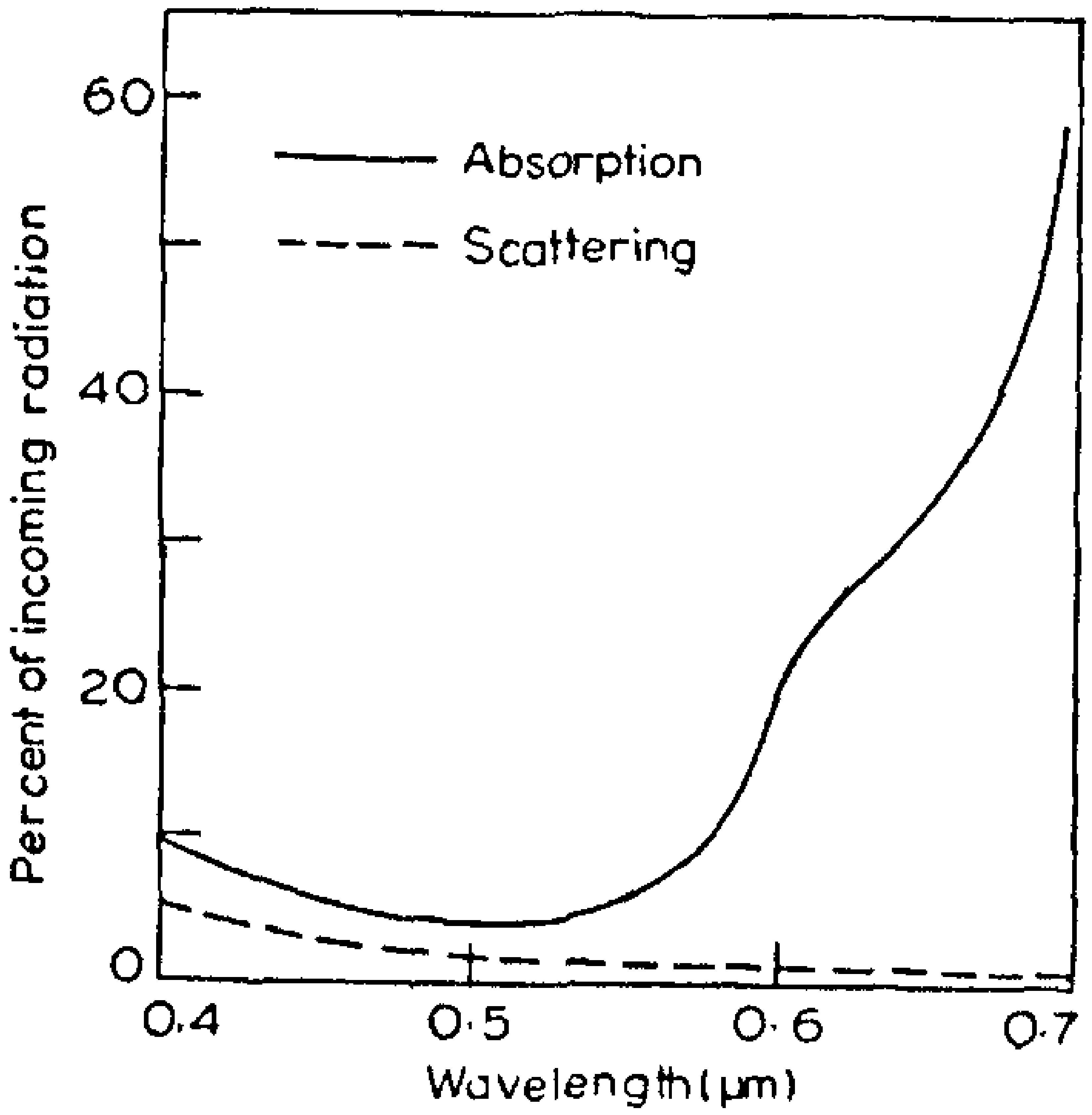

Figure 12. Absorption and scattering characteristics of distilled water.

some aspects can be studied in the visible wavelength. The distilled water absorbs very little incoming energy in the visible region below 0.6 μm, while the transmission in the shorter visible wavelength is very high for distilled water. The transmittance of natural water decreases as the level of turbidity increases. Figure 12 shows the absorption and scattering of distilled water. Figure 13 shows spectral transmittance through 10 meter depth of different varieties of waters. At approximately 0.48 μm in the blue-green region, accurate depth measurement of clear water can be obtained. In the spectral band of 0.5 to 0.6 μm, depth penetrations upto 10 meters can be obtained. In the 0.6 to 0.7 μm range, the depth only upto 10 cm can be measured.

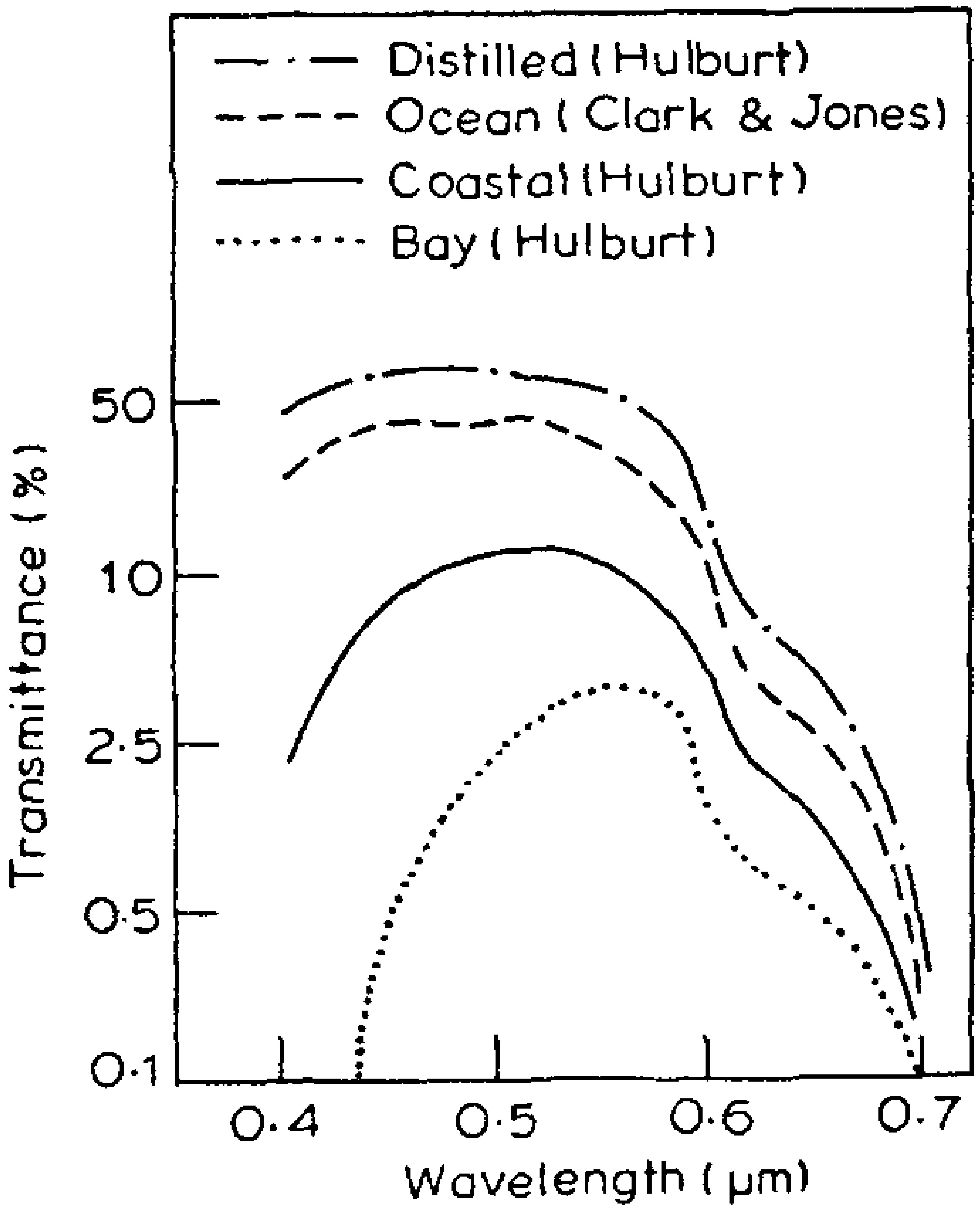

Figure 13. Spectral transmittance through ten meters of water of various types.

Figure 14 shows the spectral characteristics of clear and turbid waters. The concentration of chlorophyll in water, also affects the spectral response. Figure 15 shows the spectral response of ocean water having different chlorophyll concentrations. Similarly figure 16 shows the reflectance curve for nearly fresh snow and for two days old snow in the 0.6 to 2.5 μm region.

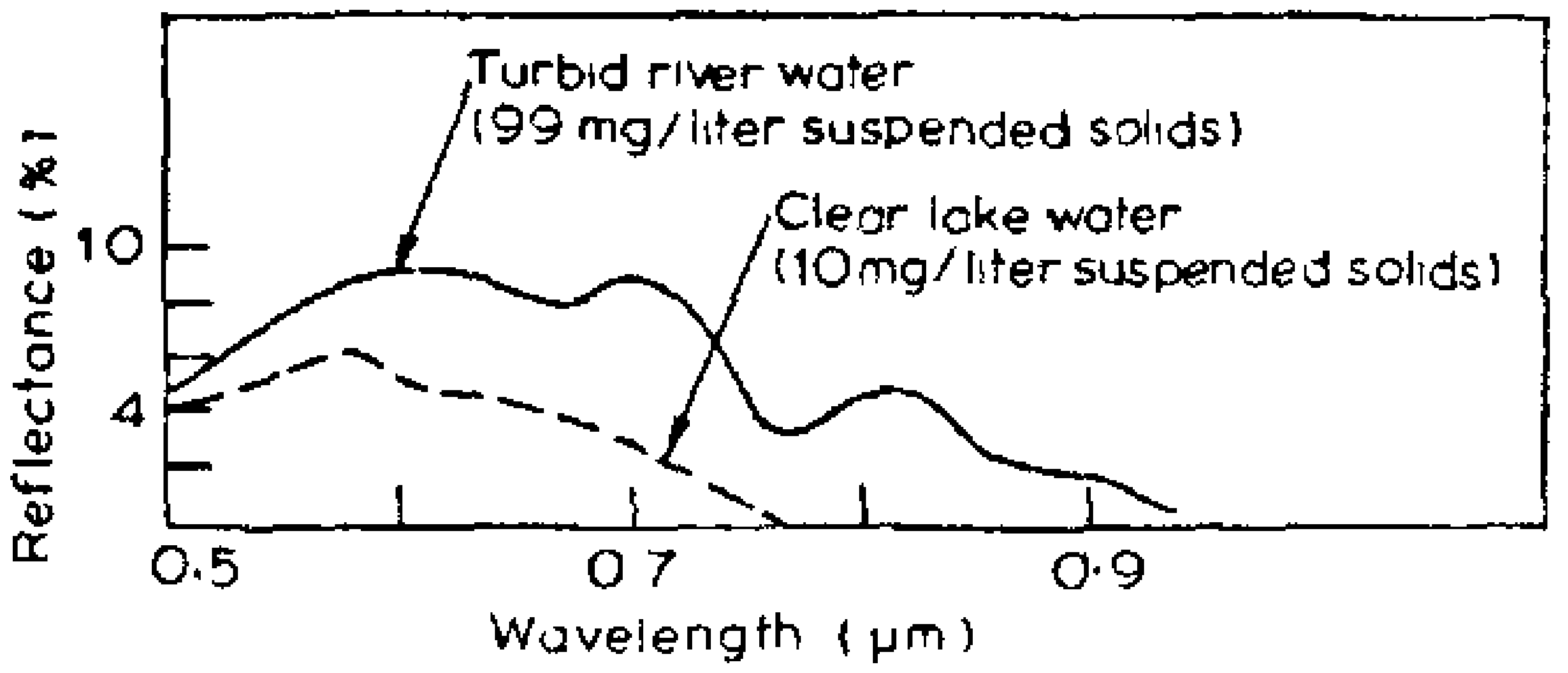

Figure 14. Spectral reflectance characteristics of turbid and clear water in the 0.5 1.0 μm wavelength interval.

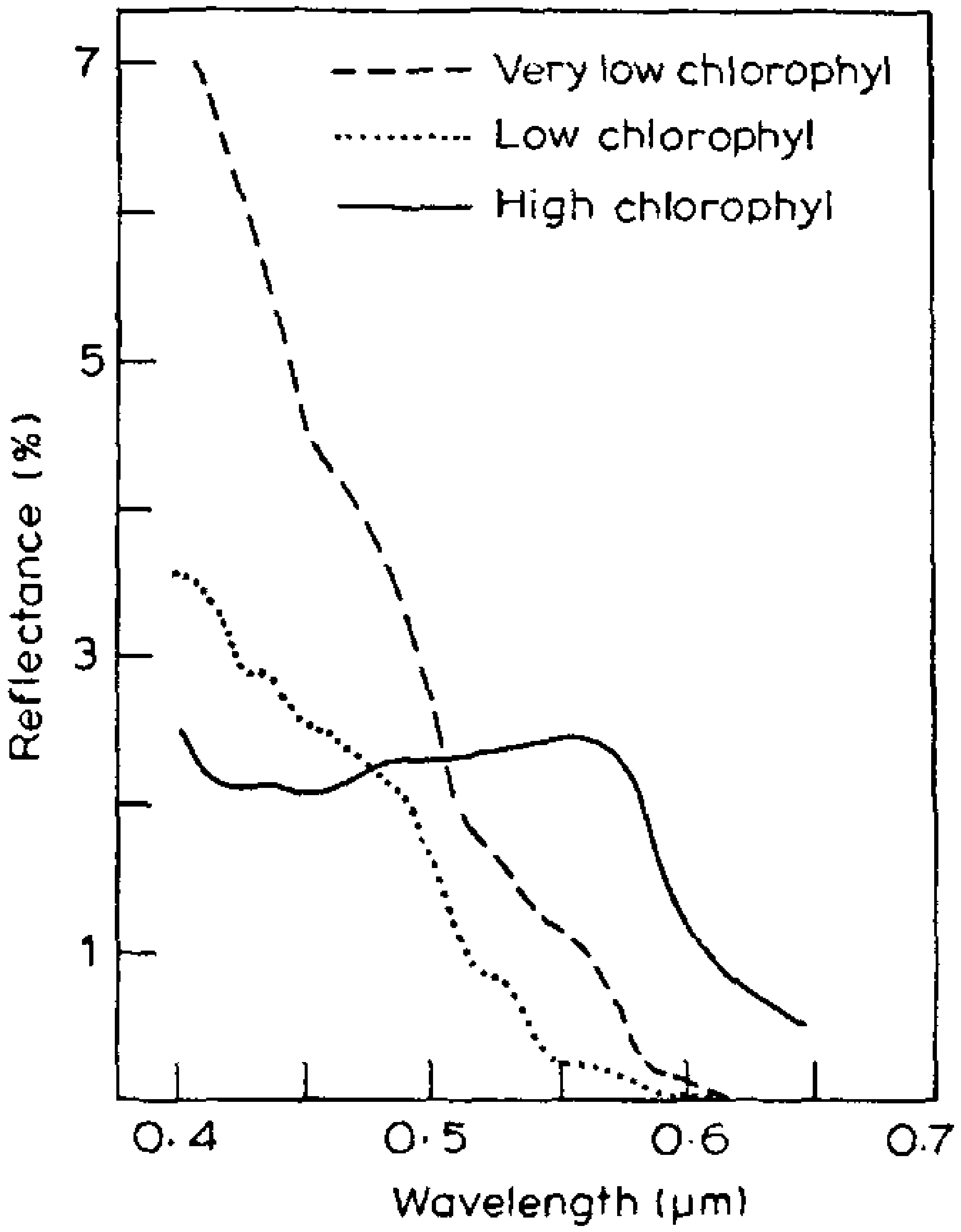

Figure 15. Spectral reflectance from ocean water having different concentrations of chlorophyll.

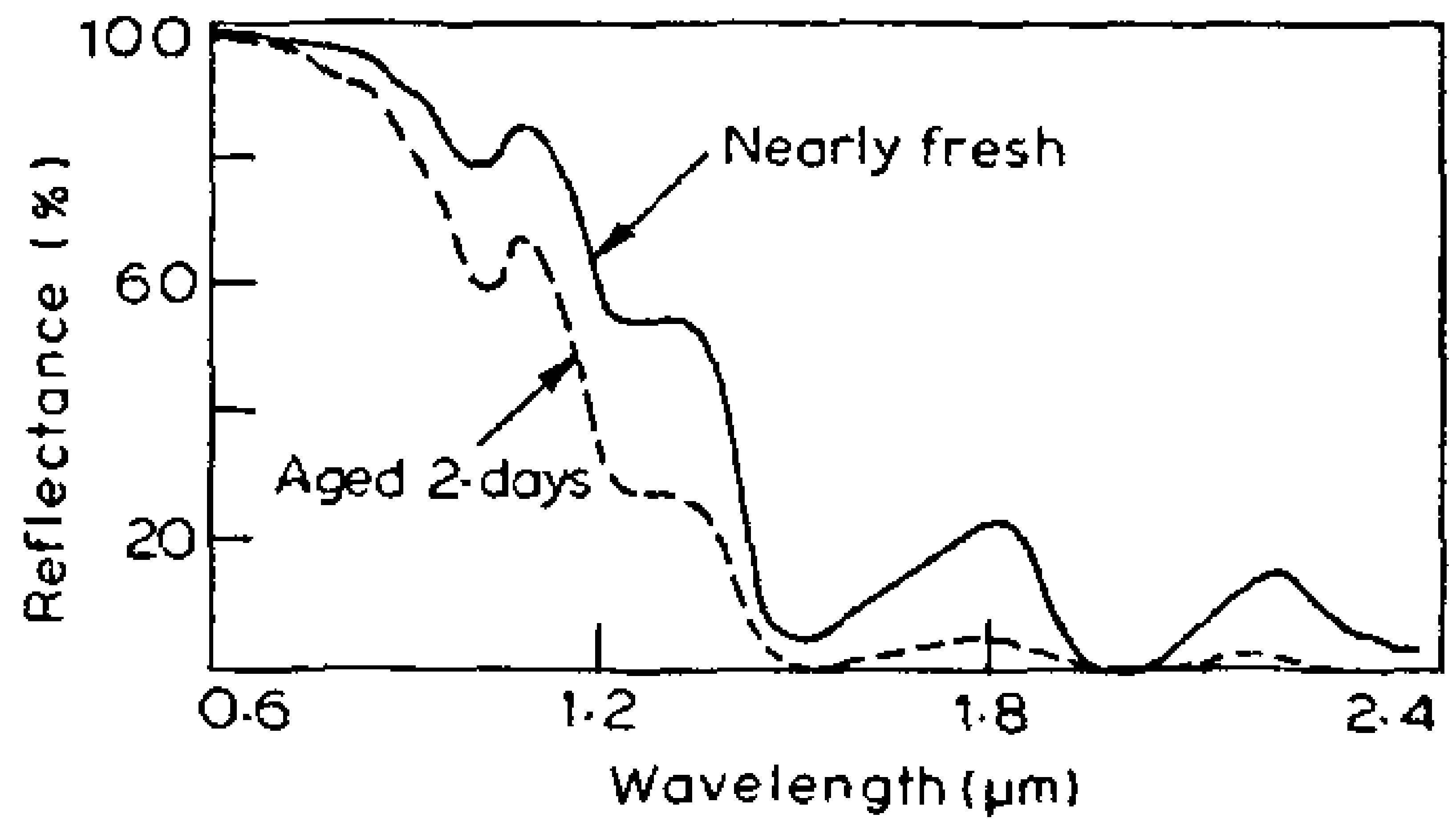

Figure 16. Spectral reflectance characteristics of snow.

ATMOSPHERE AND ITS EFFECTS ON REMOTE SENSING

(i) *Atmosphere*:

The sun is a relatively constant source of energy above the atmosphere. The amount of energy reaching the earth surface depends upon the atmospheric conditions. Through scattering, reflection and absorption, the atmosphere alters the amount of solar energy striking the earth. Further alterations occur as energy reflected or transmitted by a feature on the earth's surface travels back through the atmosphere before sensor records. The chief cause of energy reduction in the visible portion of the spectrum is scattering by aerosols, haze, smoke and dust.

The scattering process depends on the size distribution of the scattering elements, their composition and concentration, and the wavelength or wavelength distribution of the radiant flux incident on them. The combination of absorption and scattering is referred to as attenuation. Atmospheric scattering caused solely by density fluctuations in the atmosphere can be described in terms of Rayleigh Scattering Coefficient $\beta(\theta, \lambda)$ as

$$\beta(\theta, \lambda) = \frac{2\pi^2 H}{\lambda^4}[n(\lambda) - 1]^2 (1 + \cos^2\theta) \quad (3)$$

where H = no. of molecules/unit volume in the atmosphere; $n(\lambda)$ = spectrally dependent refractive index of the molecule; θ = angle between the incident and the scattered flux; λ = wavelength of incident flux.

The second scattering mechanism to be considered is Mie scattering. It occurs when the radiation wavelength is comparable to the size of the scattering particles. For the most universal situation, in which there is a continuous particle size distribution, the scattering coeffecient is given by

$$\sigma_\lambda = 10^5 \pi \int_{a_1}^{a_2} N(a)\, K(a, n)\, a^2\, da \quad (4)$$

where σ_λ = scattering coefficient at wavelength λ; $N(a)$ = number of particles in the interval a to $a + da$; $K(a, n)$ = scattering coefficient (cross section); a = radius of spherical particles; n = index of refraction of particles.

In remote sensing, Mie scattering usually manifests itself as a general deterioration of Multispectral images across the optical spectrum under conditions of heavy atmospheric haze.

The scattering element size parameter q is given by

$$q = 2\pi r/\lambda \quad (5)$$

where r = radius of scattering element; λ = effective wavelength of the radiant flux.

For nonabsorbing scattering element whose size is such that $q < 1$, the scattering process is identical to Rayleigh scattering. For $1 < q < 2$, scattering process is transitional stage from Rayleigh to Mie.

(*ii*) *Atmospheric Windows*:

Figure 17 shows spectral transmittance upto the Far Infra-red regions of the E. M. Spectrum. The molecules responsible for each absorption band are water vapour, carbon-dioxide, ozone, as indicated in the upper part of the figure. The transmission curves can be characterized by several regions of high transmission; these are known as the atmospheric windows. The transmission depends upon the amount of absorber along the path, the altitude, the angle the path makes with the horizontal and wavelength of observation. According to the theory of scattering, a particle is a most effecient scatterer when

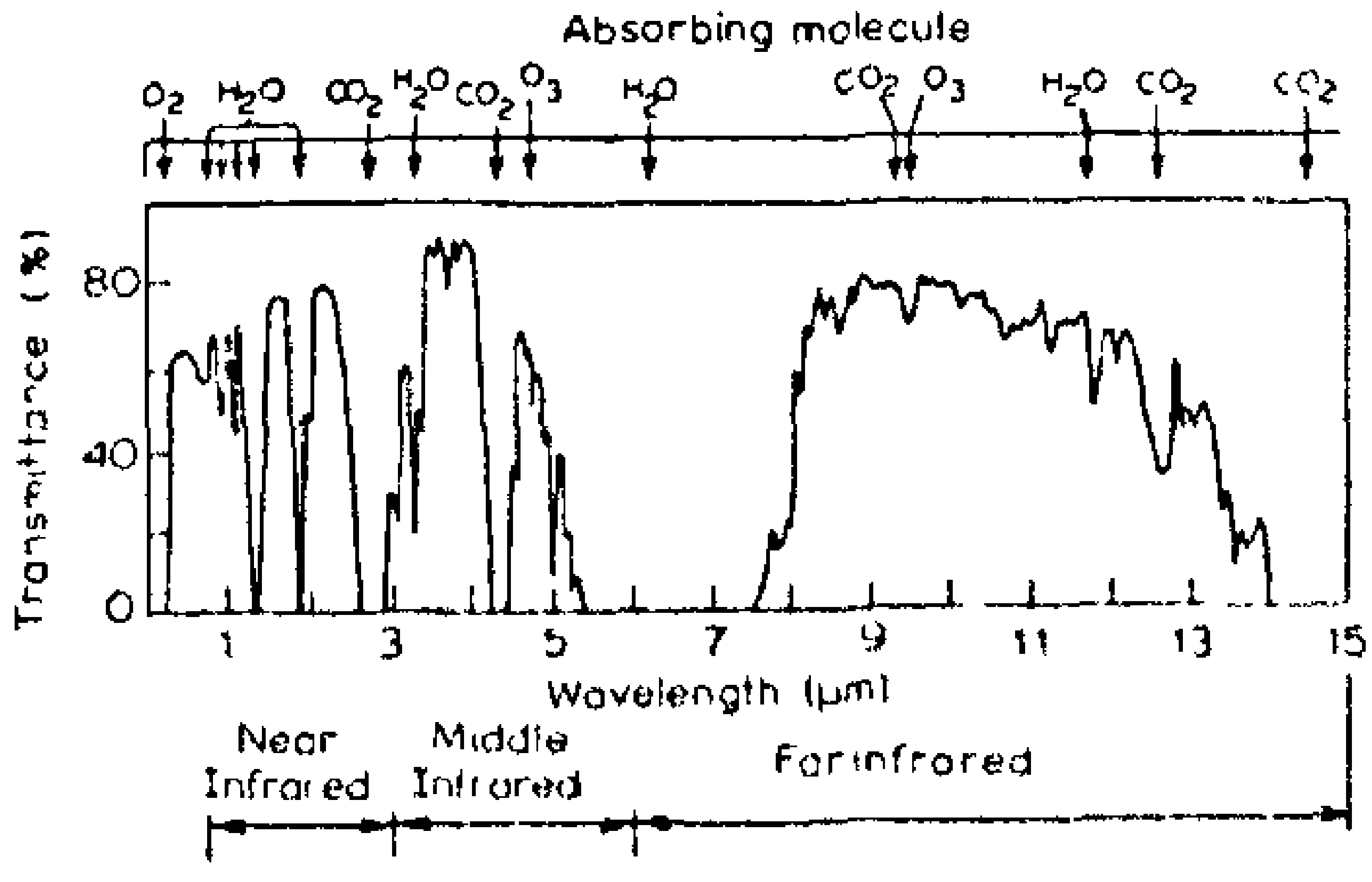

Figure 17 Transmittance through the earths atmosphere (horizontal path-at sea level length 1828)

its radius is equal to the wavelength of radiation being scattered. Since most atmospheric scatterers (haze particles) have radii that are from 0.05 to 0.5 μm, the shorter wavelengths in the visible portion of the spectrum are scattered much more than the longer wavelength of the IR. Particles like fogs, and clouds have radii ranging from 2 to 20μm so that they are very effective IR scatterers. As a result, clouds and fogs are essentially opaque in the IR with the consequence that IR sensor system, working in the Remote Sensing can never have a true all weather capability.

There are several atmospheric windows, which give the necessary spectral bands for Remote Sensing data acquisitions. The most utilized spectral windows are 0.3 to 1.3 μm and 8–14 μm.

(*iii*) *Lambert's law*:

The transmission of the radiant flux in an absorbing medium is defined using the Lambert's law,

$$\phi_z = \phi_0 \exp(-\mu z) \qquad (6)$$

where ϕ_z = incident monochromatic flux propagated in the z direction through an absorbing medium, ϕ_z = amount of flux present after distance z, μ = coefficient of absorption.

In a medium having both absorption and scattering the attention of the incident ϕ is given by

$$\phi_z = \phi_0 \exp\{-(\mu + \beta)z\} \qquad (7)$$

where ϕ_z = flux at distance z; μ = coefficient of absorption; β = coefficient of scattering. In atmospheric physics, $\beta_{\text{ext}} = \beta + \mu$ is called extinction coefficient.

(*iv*) *Atmospheric vision*

The human eye has some kind of optimization to the wavelength range $0.35\ \mu\text{m} \leq \lambda \leq 0.74\ \mu\text{m}$ in the visual band. There exist different types of opto-electronic imaging devices of actual interest to vision through the atmosphere in the wavelength range $0.35\ \mu\text{m} \leq \lambda \leq 14\ \mu\text{m}$. Vision through the atmosphere suffers from atmospheric limitations like relevant noise from imaging device, optical transfer function of the detector, amplifier and noise including that of data processing and storage. If L_1 is the initial radiance of the object and L_2 that of its surrounding, we have

$$\Delta L = L_1 - L_2 \qquad \text{(a)}$$

$$K = \frac{L_1 - L_2}{L_2} \qquad \text{(b)}$$

$$C = \frac{L_1 - L_2}{L_1 + L_2}\,. \qquad \text{(c)}$$

The radiance difference ΔLin equation (a) is usually used in IR region as a thermal contrast. The equation (b) is the Universal contrast and is used mostly for the analysis of vision with human eye. The equation (c) often called modulation is being introduced to atmospheric optics as contrast in the context of the application of optical information theory, including the concept of OTF, which describes an optical system by modulation transfer function and phase transformations combined in the OTF

PHYSICAL PROCESSES OF ATMOSPERIC VISION:

(*a*) $\lambda \leq 3\ \mu$m

In this range, the thermal emissions in the scene can be neglected because the emissions are very small even for highly emitting black objects. Usually reflectivity of natural and artificial objects are rather high and very considerable for $\lambda \leq 3\ \mu$m.

At the observation site, the apparent radiance is given by

$$L_i = \tau L_i + L^A \qquad (8)$$

where $\tau \leq 1$ is the spectrally relevant atmospheric transmission, L_i^T = initial radiance, T = indicates target; L^A = Path radiance due to atmospheric scattering.

The path radiance or Luminance for visual band for a horizontal path is

$$L^A = L^H(1 - \tau) = L^H\{1 - (\exp - \sigma R)\} \qquad (9)$$

where L^H is the horizon radiance or luminance; τ = transmission along R; σ = extinction coefficient.

Figure 18 shows schematically atmospheric vision for $\lambda \leq 3\ \mu$m.

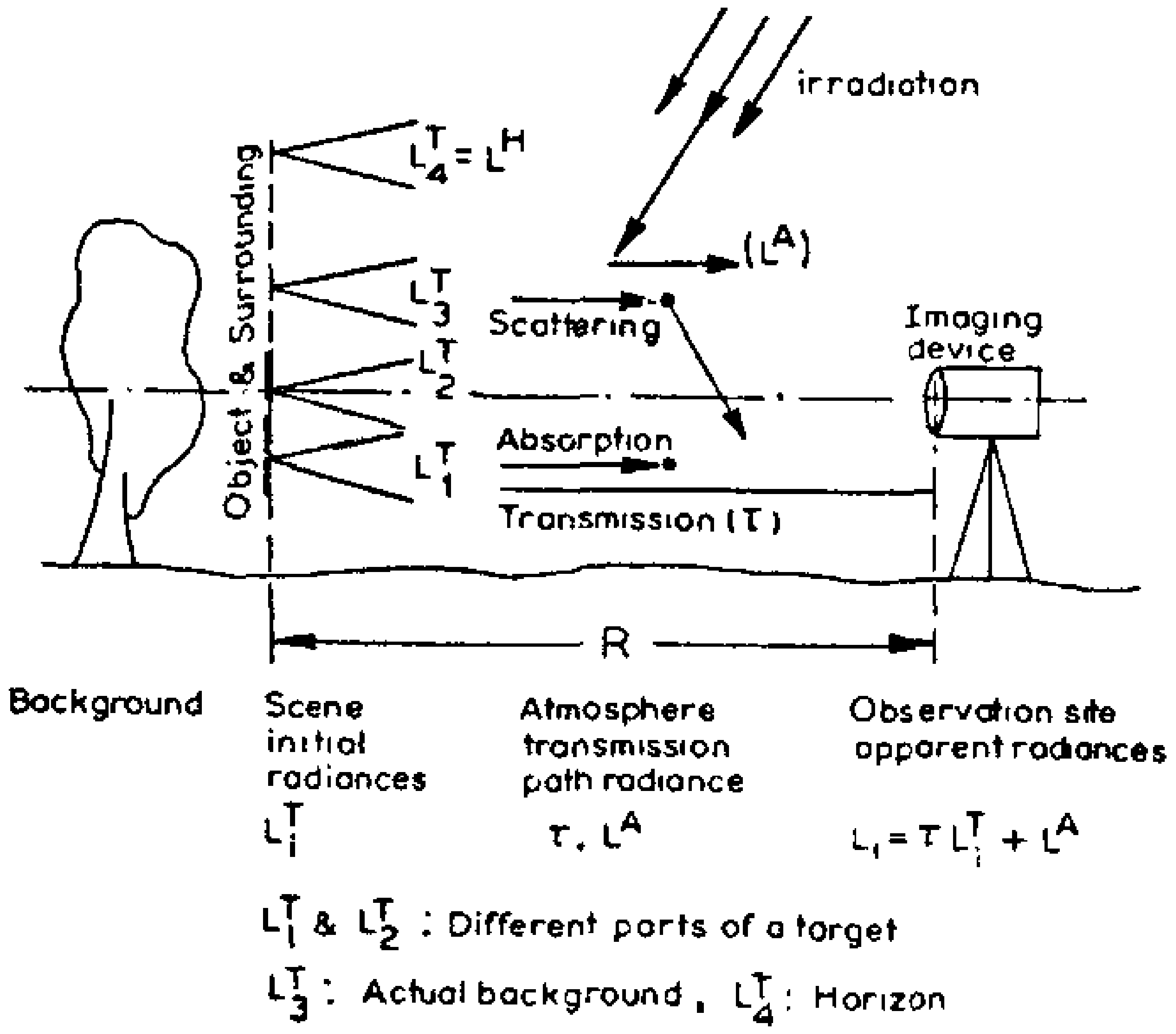

Figure 18. Atmospheric vision for $\lambda \leq 3\ \mu$m.

(*b*) *For* $\lambda \geq 3\ \mu$m

In this range, the thermal emission can no longer be neglected. The reflected radiation in this range are much smaller as compared to emission of radiation and hence can be neglected. The thermal emission in the scene now determines the radiance L_i^T. Different temperatures and/or different emissivities produce radiance differences ,ΔL^{T*}. The atmosphere produces a path radiance L^A mainly by atmospheric emission rather than atmospheric scattering. The later can usually be neglected. The radiant fluxes passing the atmosphere are attenuated, mostly due to absorption. In the atmospheric window and especially with precipitation, scattering must also be considered. At the receiver site the radiance L_i can be described by

$$L_i = \tau L_i^T + L_A \tag{10}$$

which is identical with the equation (8), however the exponential expression $\tau = \exp(-\sigma R)$ can no longer be used as a good approximation for a broad wavelength band because of the complicated absorption spectrum in the IR. Figure 19 schematically shows the atmospheric vision for $\lambda \geq 3\ \mu$m.

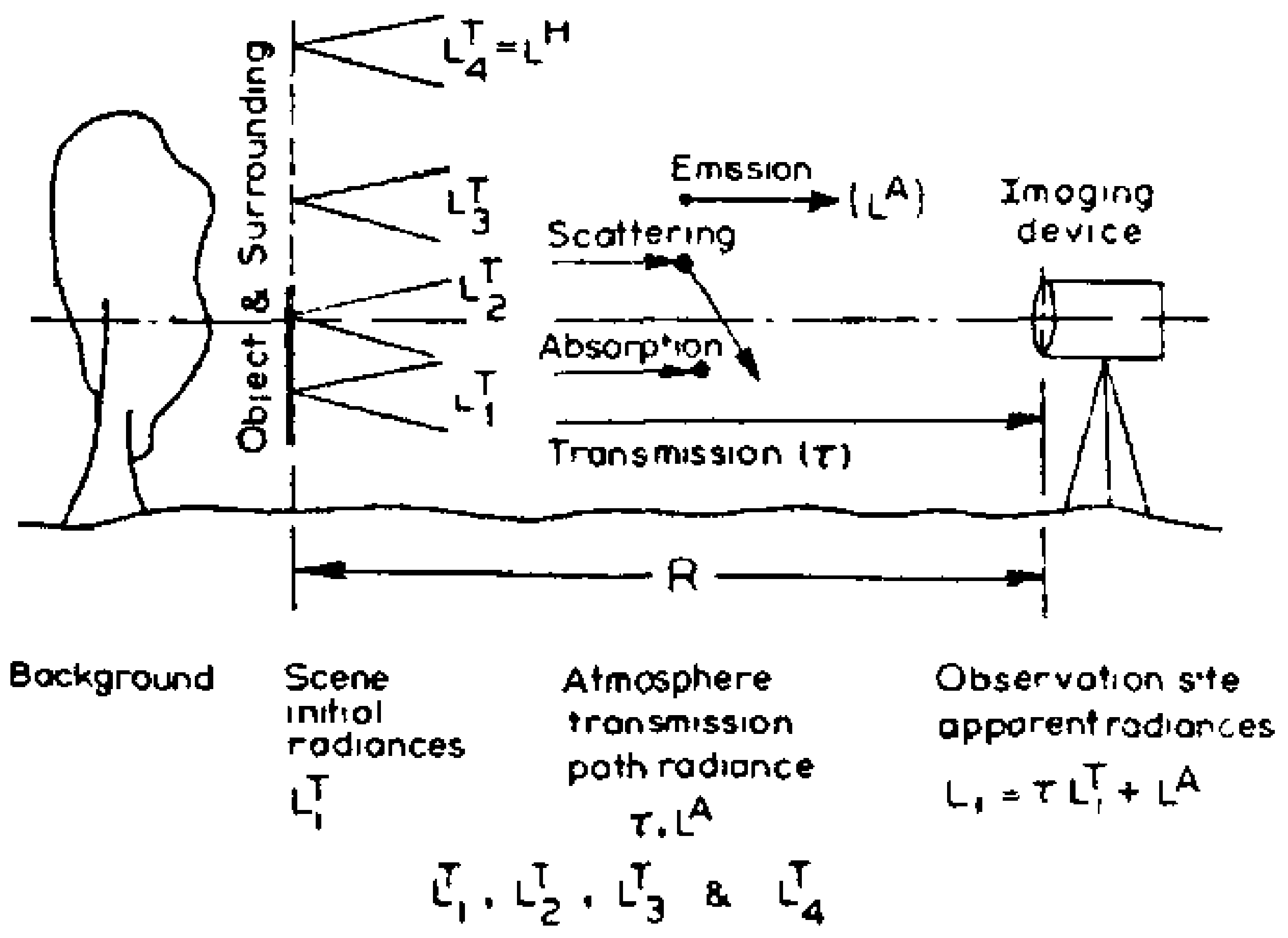

Figure 19. Atmospheric vision for $\lambda \geq 3\ \mu$m.

REMOTE SENSING SENSORS:

(*i*) *Imaging and Non-Imaging Sensors*

Radiation sensors are instruments that measure the intensity of radiations leaving a surface or object as a function of time, wavelength, space, geometry, including angular orientation of the target w.r.t. the observer and polarization of the radiations. No single instrument can do all these things well or even satisfactorily. For most applications therefore, some parameters are stressed in each instrument at the expense of the others. Sensors are therefore grouped into imagers, which stress spatial resolution and non-imagers which stress time and wavelength resolution and sometimes polarization. Sensors may be classified as active or passive, Image or Non-Image forming, commercial or military. Active sensor provides its own source of illumination, whereas passive sensor does not. Figure 20 shows general components of optical electronics systems. The image forming systems like photographic systems, multispectral scanner, and electron imagers are described here.

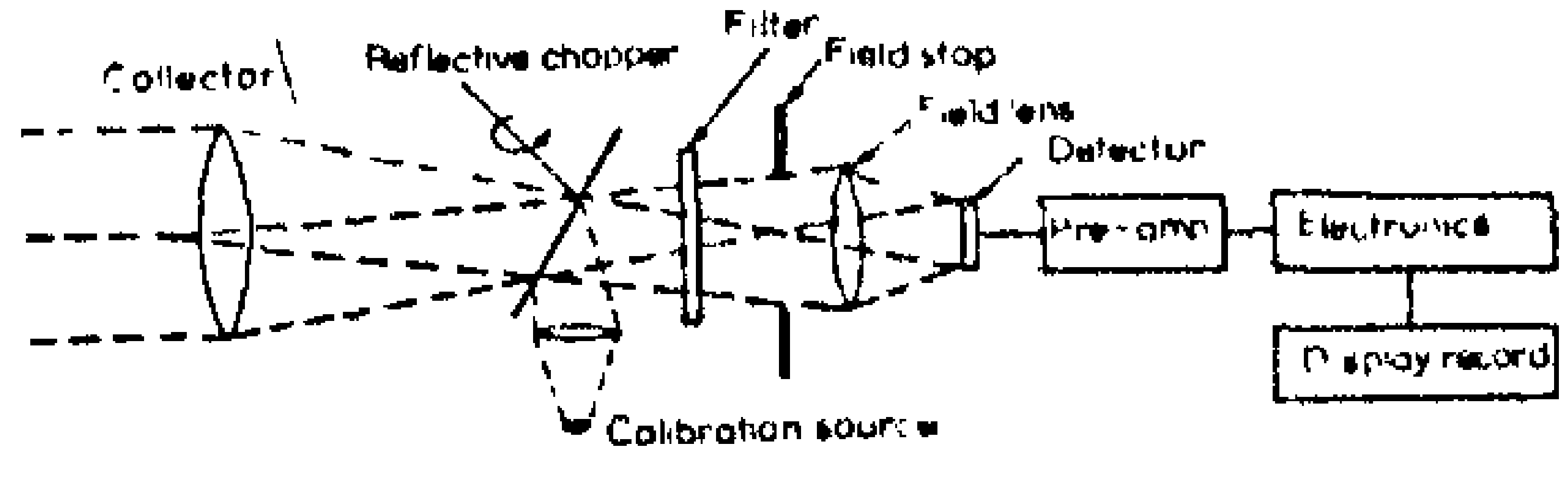

Figure 20. General components of optical-electronic sensors.

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*Often called thermal contrast.

(*a*) *Photographic systems*:

The technology of remote sensing actually originated in the science of photo-interpretation. Camera systems remain popular for aircraft Remote Sensing programs inspite of the increased use of the satellite imageries using Electro-optical image recording systems. In photographic systems, the film functions as a detector, the lens as an optical system. A photographic system is basically a framing system where all the data in an image are acquired simultaneously. The limitation being the restriction of a relatively limited spectral range compared to a multispectral system. At the same time, the photographic system has an extremely high spatial resolution.

The optical system: Photographic lens arrangements are shown in figure 21. The intensity at the film plane is given by

$$I \propto \frac{A_g\, A_f}{H^2} \cos^4\theta \qquad (11)$$

where $A_g \cos\theta$ = projected area viewed on the ground by the camera; $A_f \cos\theta$ = area of the image of the ground scanner, element for $\theta = 0$; $H/\cos\theta$ = distance from the camera to the ground.

The above $\cos^4\theta$ Law says that as one increased the angle between the image and the optical axis of the camera, the intensity of image on the film falls off as the fourth power of the cosine of the angle from the optical axis to the image element. This means that the edges of the image are considerably dimmer than the center of the image. This can be compensated either by using special filters placed over the lens or by the special steps taken in the lens design.

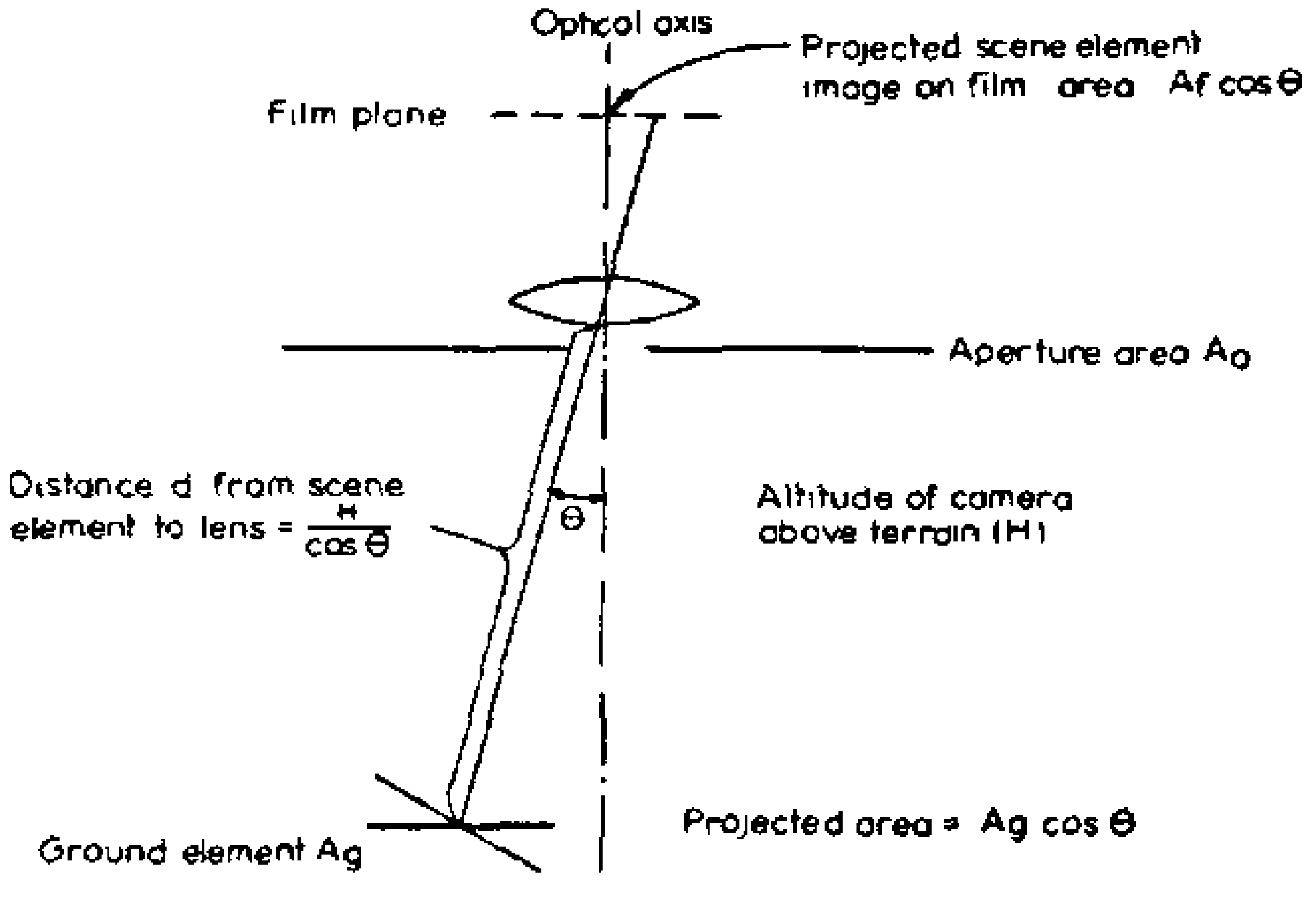

Figure 21. Angular dependence in a simple photo graphic system.

Film, the Detector: Photographic film serves as a radiation detector in place of the photon detectors in the scanner system. Silver halide is the basic photon detecting system in a film. A basic black and white film sensitive only to blue radiations and relatively insensitive to red is called orthochromatic film. Special sensitizing procedures can be applied to emulsions of Black and White film to make them sensitive to IR radiations upto approximately 0.9μm. The panchromatic B/W film has limited tonal range while it gives sharp definition and good contrast imagery. The IR B/W films also have limited tonal range and it is difficult to determine the correct exposure. At the same time, IR B/W films are inexpensive and very useful for vegetation and water body studies. A colour film has three sensitized layers, each being sensitive to red, green and blue. In the case of colour IR film, the last layer is sensitive to IR radiations (upto 0.9μm), the middle layer is sensitive to red and the third layer is sensitive to green radiations. A yellow filter is used to separate out blue component from the colour IR film. The colour film is found to be excellent for interpretation of imageries due to good contrast and tonal range. False colour IR film has sharp resolution and is very suitable for vegetation, and soil moisture studies.

(*B*) *Multispectral Scanner*:

Multispectral scanner produces imagery in a sequential fashion. The target is scanned in raster fashion (a line at a time), usually with an optical mechanical system. Radiation passes through converging optics which establish the instantaneous field of view (IFOV). The total field of view (TFOV) is established by scanning motion of the optical system. The radiation is then dispersed into its spectral components using prisms, gratings, dichroics, or filters. An array of detector senses the dispersed radiations. The detectors are arranged spatially so that the appropriate detector can sense the wavelength region to which it is sensitive. The signals from each detector are amplified, processed and then recorded on board the vehicle or transmitted by telemetry to a receiving station. The calibration source and scene are scanned by opto-mechanical system. The motion of the vehicle provides the along-track scan motion of the sensor; whereas, line scanner itself develops across track scan motion. Figure 22 shows the block diagram of the Multispectral Scanner (MSS). Figure 23 shows the MSS scanning arrangement used with Satellite. The spectral response of the visible and NIR bands in the Landsat MSS are shown in figure 24.

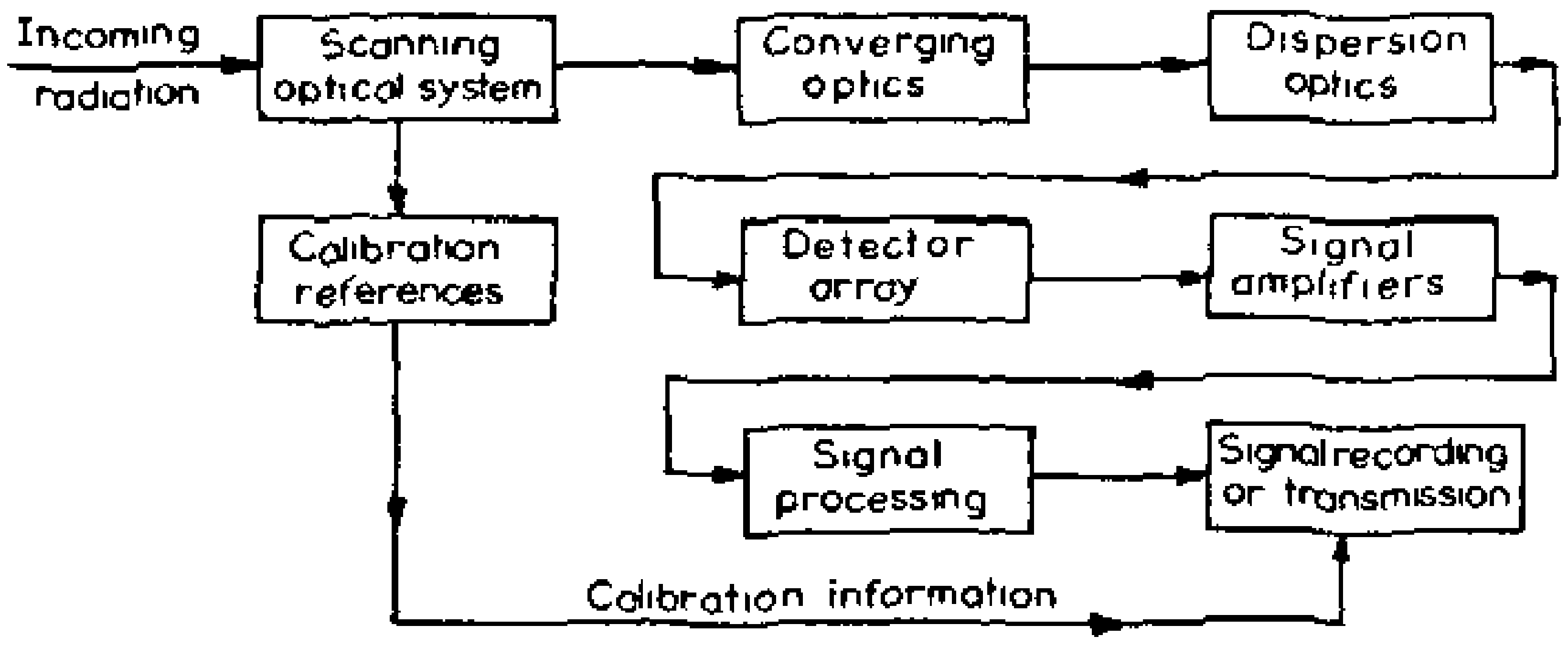

Figure 22. Functional block diagram of a multispectral line scanner.

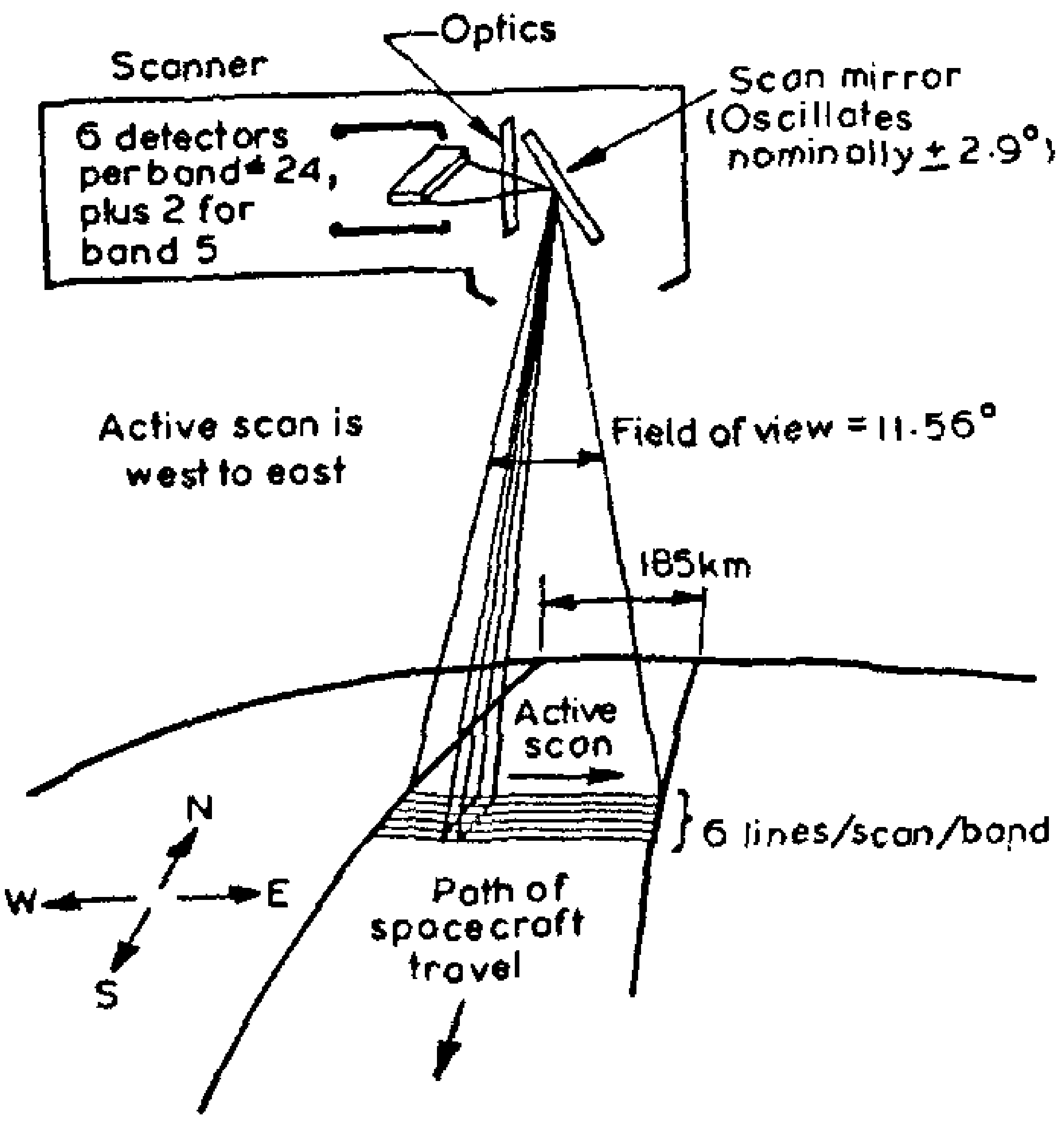

Figure 23. MSS scanning arrangement.

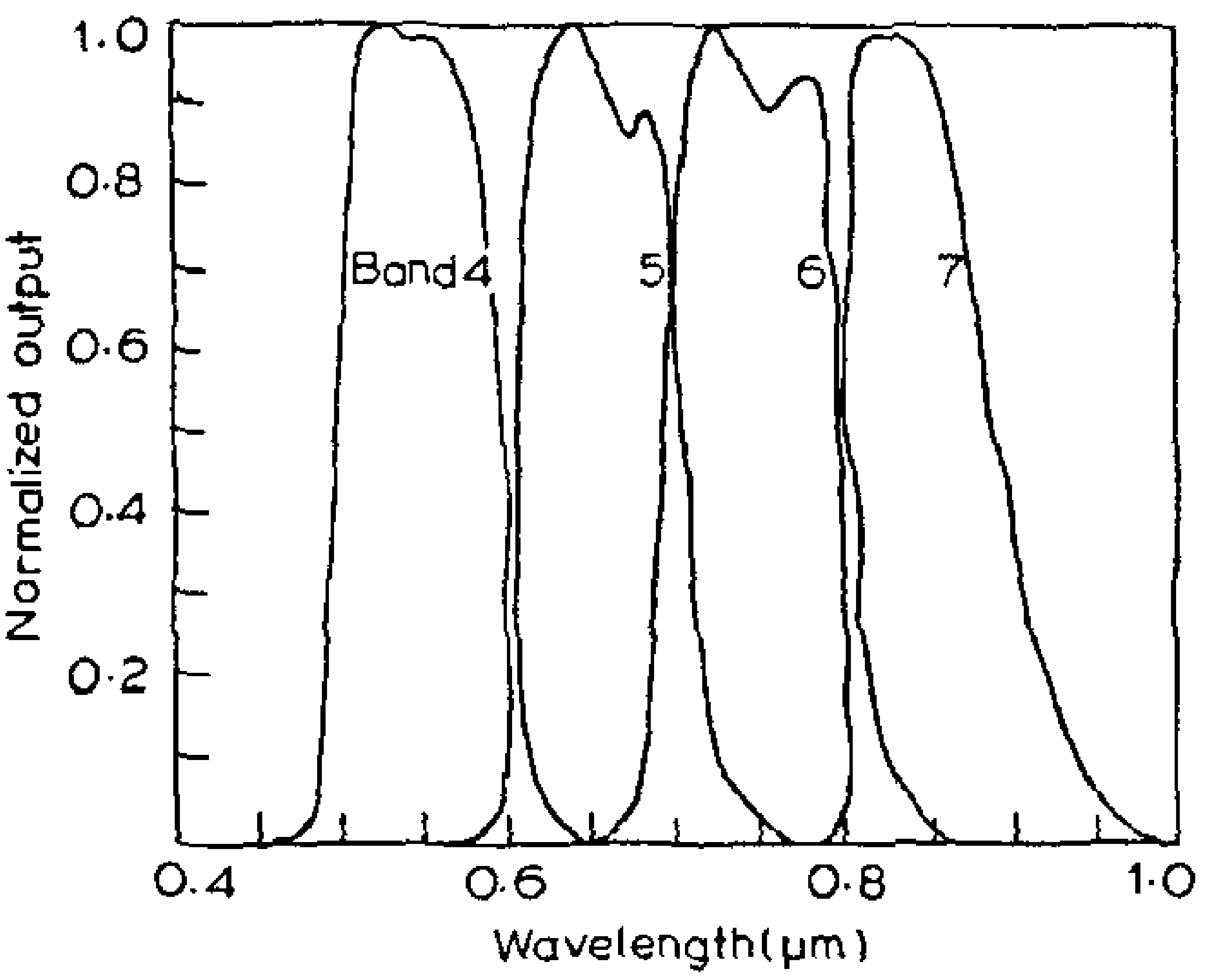

Figure 24. The nominal spectral responses of the visible and near infrared bands in the landsat MSS.

(*c*) *Return-Beam vidicon*:

Return Beam Vidicon (RBV) is one of the recent additions to the large family of devices falling in the general category of electron beam imaging sensors. It contains a photo-conductive or photo-emissive surface onto which the scene of interest is focussed optically. Generally external components are used to focus and deflect the readout electron beam that scans the image on the photo sensitive surface. The readout electron beam is generated in an electron gun, accelerated, focussed by an electron lens and then electro-statically or electro-magnetically deflected to perform a rectangular raster scan. RBV have been used in the first three series of Landsat Satellite for Remote Sensing applications. Figure 25 shows the optical schematic of the RBV. As shown in the diagram electron beams are reflected from the backside of the

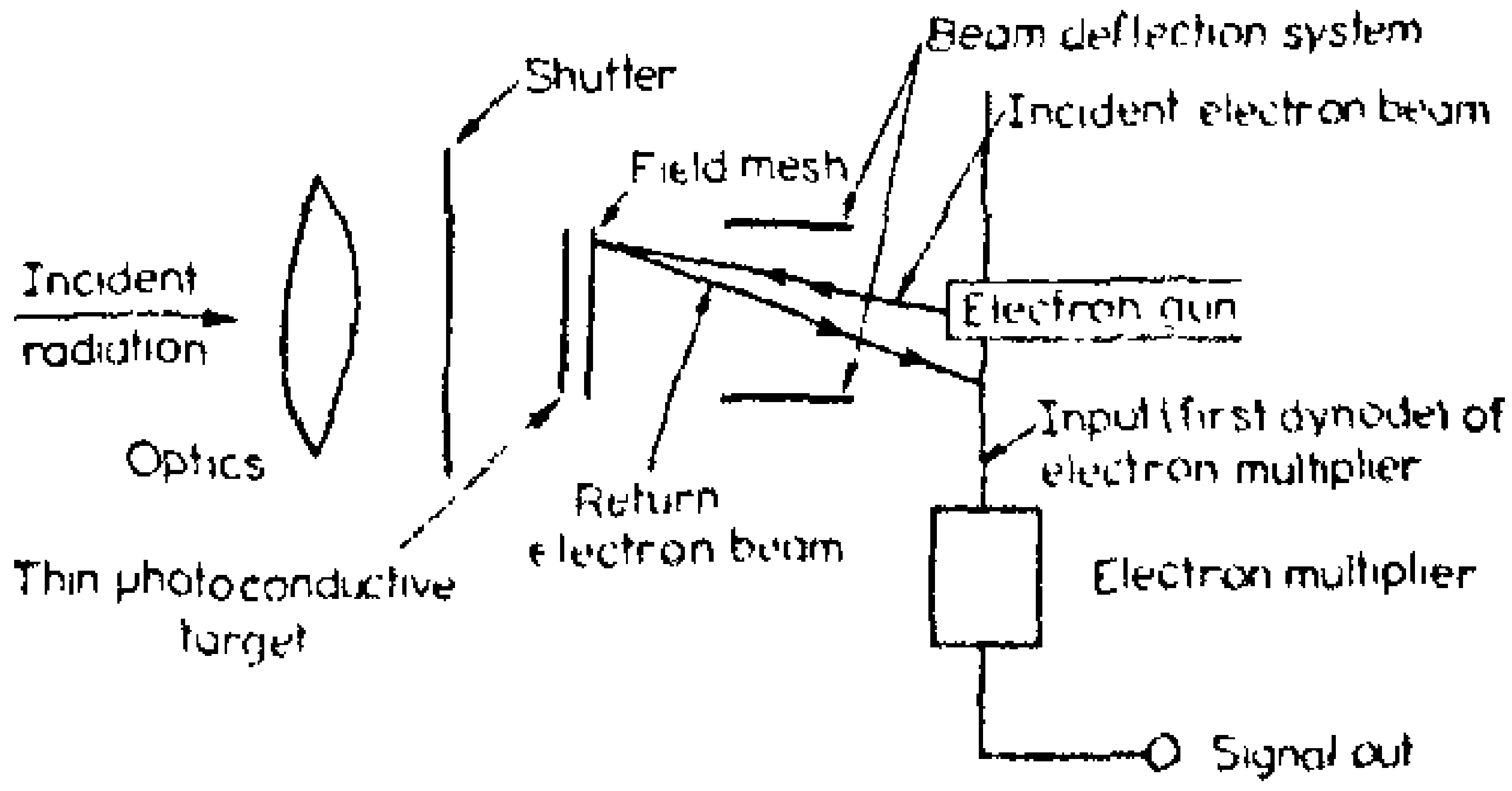

Figure 25. Optical schematic of a return beam vidicon (RBV).

target to carry the image describing signals. The reflected beam is detectably weakened when charge is left behind the light sensitized area of the photoconductor. Complete erasure is obtained by discharging the photo conductor. The surface is then scanned with a relatively high beam current to prepare for the next exposure.

The advantage of RBV over other electron beam imagers is its high spatial resolving power (100 to 120 lines pair/mm). For a given ground resolution requirement, the size of image forming optics can be much smaller for RBV system. It has two possible disadvantages. First is that Antimony Sulphide Oxysulphide (ASOS) photoconductor has a high capacitance that causes erasure and subsequent prepare time to be long of the order of 5 to 15 sec. A second disadvantage, is that the focus coils of the tube consume about 30 watts of power.

APPLICATIONS OF REMOTE SENSING

Remotely sensed spectral measurements can be a source of useful information for many applications. While technology is still developing and many improvements in its capabilities are foreseen, there is much evidence, of its use for various operational projects. The applications of Remote Sensing include agriculture, forestry, geology, mineral resources, hydrology, water resources, geography, cartography, meteorology and military. Some of these are briefly discussed here.

(*a*) *Agriculture and Forestry*:

The applications of remote sensing to agriculture and forestry include crop identification and area estimation, assessment of crop condition and yield potential, detection of diseases and other crop stresses and soil mapping. The use of multistage sampling with a combination of ground, aircraft and satellite imagery has been reported to be quite useful for such studies. The IR aerial photography could be used to differentiate healthy and rust-infected small grain. The soil moisture is one of the important resources affecting the food grain production. Remote Sensing technique helps in measuring global soil moisture. Soil influences greatly the distribution and crop yield.

(*b*) *Landuse Inventory and Mapping*:

One of the major tasks confronting planners and administrators of local, state, and national government agencies is the acquisition and analysis of information upon which to base decisions concerning community and economic development of human and natural resources. Current methods are too time consuming, costly and inefficient to be effective. Land use inventory and mapping, using remote sensing techniques is quite helpful to substitute the old practice of land use studies. There is a considerable saving in time, and cost of maps, produced from LANDSAT data as compared to interpretation of aerial photography.

(*c*) *Hydrology and Water Resources*:

Remote sensing data are used for monitoring and management of water resources. It is used for flood area mapping, snow cover measurements for water runoff estimation, determination of the aerial extent of surface water and wet lands, detection of water pollution and mapping of water surface temperature.

(*d*) *Mineral Resources, and Geological Structures*:

Aerial photography has been used in geological surveys for many years. Recent advances indicate that satellite acquired imagery can be effectively used for many geological tasks. The wide area coverage in a single LANDSAT imagery is particularly advantageous for the detection and mapping of lineaments. Other examples include reconnaissance mapping in inaccessible regions, map revisions, regional or synoptic analysis of crusta features, assessment of dynamic surface processes, and systematic search for minerals.

(*e*) *Meteorolgy*:

Satellites provide meteorologists with a data source unmatched at comparable and temporal coverage by any existing or practical alternate source. There are limitations, however, both instrumental and fundamental, imposed on the achievable resolution and accuracy. The data are used for (1) synoptic meteorology where satellite observation of clouds provide measures of winds, cyclogenesis, and rainfall estimation; (2) atmospheric profiling wherein vertical profile of temperature, humidity, and certain gaseous constitutents are provided; (3) radiation budget or the energy exchange between the earth and the space-sun environment and (4) surface features of importance to meteorology, temperature, soil moisture, and sea ice coverage.

(*f*) *Military applications*:

Reconnaissance by means of aerial photography has been practiced by the military, since a long time. Cameras designed specifically for use in aircraft were in production by the end of 1915 and saw extensive use in World War I. IR Black and White films for aerial reconnaissance have a long wavelength cut-off at 0.9 μm. By proper choice of the sensitizing dye, it is possible to produce emissions having cut-off as long as 1.35 μm.

Camouflage is used in a military situation to confuse or deceive an observer. The techniques of camouflage include complete concealment, dummies, nonfunctional structural additions to make the object look like something else, and covering to blend the object with its surroundings. Among the means used to blend an object with its surrounding are the direct application of paints, the use of overlying nets supporting strips of various painted fabrics, and simply covering the objects with foliage cut from the surroundings. It is done to match an object with its surrounding environment. For human eye, it is difficult to detect and identify. Through use of IR B/W and False colour IR film such changes can be easily detected since the reflectivity of the various objects is different. Figure 26 shows the spectral reflectance of foliage and paints. There is also a Russian-produced false colour film having only two layers known as spectrazonal film. One layer has panchromatic type response extending to 0.65 m. The second layer extends to 0.8 μm. On the spectrazonal film, conifers appear green, deciduous foliage appears yellow, orange or red, and high reflecting camouflage paints appear nearly white.

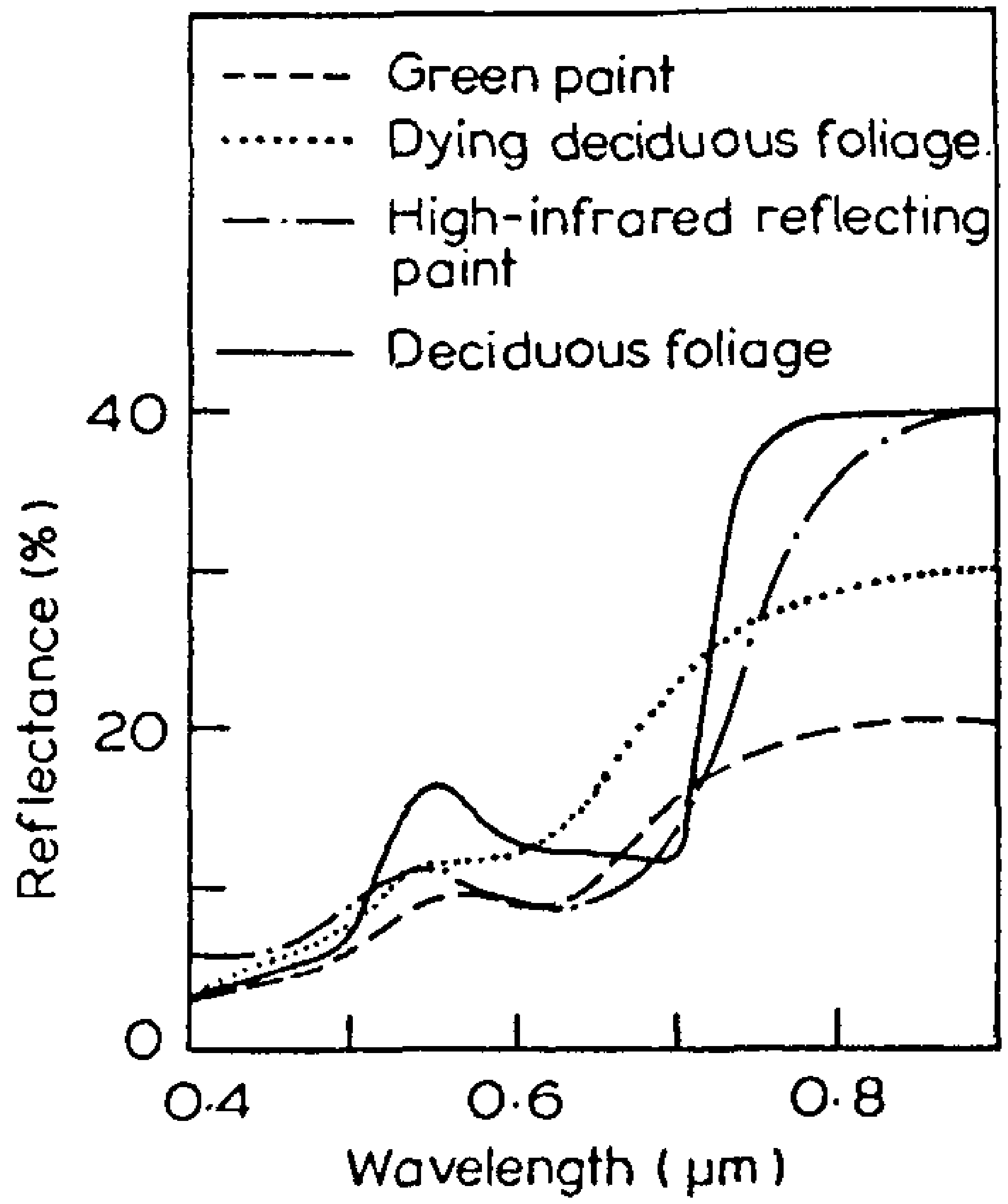

Figure 26. Spectral reflectance of foliage and paints.

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