ENGINEERING RESEARCH INSTITUTE
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# THE INFRARED REGION OF THE ELECTROMAGNETIC SPECTRUM

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Electronic Defense Group
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This is not a final report. Further investigation may make it desirable to have this report revised, superseded or withdrawn.

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# ABSTRACT

An introduction to the infrared region of the electromagnetic spectrum is presented. Basic infrared theory and definitions are given, and a general discussion of infrared targets, backgrounds, and detectors is included.

# THE INFRARED REGION OF THE ELECTROMAGNETIC SPECTRUM

## I INTRODUCTION

This report was written to serve as a means of introduction to the infrared region of the electromagnetic spectrum. It is intended to provide some of the basic terminology and physical concepts needed for reading the technical literature on specific problems. No previous knowledge of infrared is assumed, since this report is intended specifically for technical personnel who have not worked with infrared frequencies but who may be presented with some problems and devices in this frequency range. It is hoped that this brief treatment will ease the transition into the infrared field and thus provide a more rapid and efficient introduction than is generally available from any other single source.

## II THEORY AND DEFINITIONS

The infrared region extends rather roughly from the lower (in frequency) end of the visible spectrum, 0.8 microns ($3.75 \times 10^{14}$ cps), down to approximately 300 microns ($1.0 \times 10^{12}$ cps) where radio frequencies may be considered to begin. Its inclusion makes the electromagnetic frequency spectrum continuous from dc through audio, radio, infrared, visible and gamma rays (x-rays).

Perhaps the most significant change which occurs as we pass from "radio" into infrared is the introduction of quantum phenomena. Since Max Planck's postulation of the quantized state of electromagnetic energy a duality has existed in the description of electromagnetic radiation. Some classic experiments are explained by wave phenomena and others by particle theory. None are explained by both. If we keep in mind this duality, then what appears to be a distinction between "radio" and infrared disappears. Throughout the infrared region, and up into higher frequencies, the duality is necessary to explain observed occurances. At radio frequencies the wave theory alone is sufficient.

It might be well here to try to establish the reasons for the present interest in the infrared region[1]. Infrared radiation is produced by

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[1] Although existence is considered a sufficient stimilus for investigation by most "pure" scientists; the engineer, being responsible for useful devices, must of necessity consider relative usefulness of various phenomena.

bodies which are "hot". All objects which have a temperature radiate energy in the electromagnetic spectrum. Most "hot" objects in our common experiences radiate with frequencies in the infrared region. Thus all of the objects in our environment are active transmitters of electromagnetic radiation. The physical mechanism for this radiation is molecular vibration. Whereas electron vibration frequencies generate the shorter wavelengths, visible and higher, the frequencies associated with infrared radiation are produced by the vibration of atoms and molecules. This radiation is actually quantized, although as the wavelengths get longer a continuous wavelength model is generally sufficient.

It is natural, then, to investigate this radiation as a means of detection. Bodies between nearly absolute zero and about 4000 degrees centigrade radiate the majority of their energy in the infrared region. Note that we have indicated that objects radiate with more than one frequency. Actually, every hot body will radiate with a continuous spectrum of frequencies. Thus a body at 4000 degrees centigrade may have its highest magnitude of radiation at 1.0 microns ($3 \times 10^{14}$ cps), but it will also emit radiant energy at all other frequencies to a lesser extent. The radiant energy from "hot" bodies thus is characterized by a curve showing radiant energy vs frequency or wave length[2]. An integral taken over the entire curve will yield the total radiated energy. A typical curve of radiation versus wavelength is shown in Fig. 1.

Several fundamental physical relationships exist describing the radiant energy curve. The term "black body" is introduced to describe an object which absorbs all of the radiant energy that falls upon it. Such an object cannot be realized but is a convenient standard for comparing real radiating and absorbing bodies. Real objects are compared to black-bodies through the use of the total emittance of the non-black body $\epsilon$, where

$$\epsilon = \frac{R_n}{R_b}$$

$R_n$ and $R_b$ are the rates of emission of radiant energy per unit area for the non-black body and black body, respectively. It was shown by Kirchhoff in 1858 that for black bodies the rate of incidence of radiant energy is equal

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[2] From this point on in this report wavelength will be specified in microns instead of in frequency. The conversion factor is: one micron = $10^{-4}$ centimeters. This agrees with most texts and permits the use of more reasonable numbers.

to the rate of emission of radiant energy. Thus the black body as described above is also an emitter of radiant energy with the maximum possible radiancy for a given temperature. Kirchhoff further showed that, for non-black bodies, the total emittance at a particular wavelength, $\epsilon_\lambda$, is equal to the total absorptance at that wavelength, $\alpha_\lambda$. Thus for an object at a 1000° K, in a region of the spectrum where the emittance is 40% the absorptance is also 40%. The curve shown in Fig. 1 is for any black body at 4000° K. A non-black body at 4000° K will possess a different curve depending on how its emittance, or absorptance, varies with wavelength.

It was established in 1884 by Boltzmann that the relationship between radiancy and temperature was a fourth power of the temperature.

$$R_b = \sigma T^4$$

where $\sigma$ is Boltmann's radiation constant, $5.673 \times 10^{-12}$ watt $cm^{-2}$ $(K^o)^{-1}$, and T is the absolute temperature in degrees Kelvin. Actually the radiant energy passing between any two bodies is proportional to the difference of the fourth power of their temperatures.

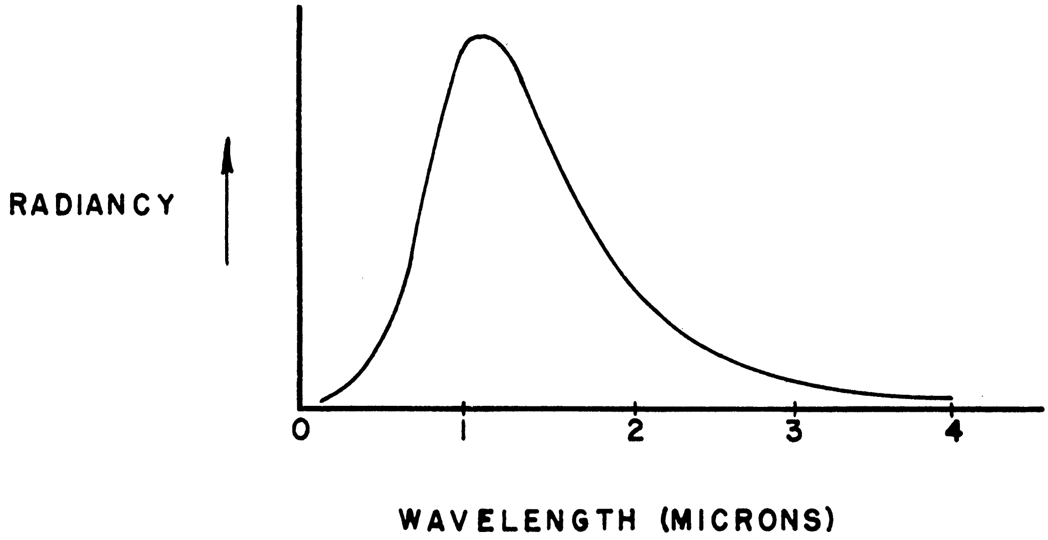
Wilhelm Wien in 1896 announced a relationship for the spectral curve, Fig. 1, yielding the spectral distribution for various temperatures of a black body. Utilizing a Maxwellian distribution for radiant energy Wien arrived at the relationship

$$R_\lambda = T^5 \; F \; (\lambda T)$$

F ($\lambda$T) is a functional relationship yielding the shape of the curve. This equation indicates that the vertical scale of Fig. 1 will expand with the fifth power of the temperature and the horizontal scale will contract with the first power of the temperature as shown in Fig. 2. The total area under the curve is thus proportional to the fourth power of the temperature as predicted by Boltzmann. A corollary relation gives the maximum radiancy at the location $\lambda_{max} T$ = constant = 2884.1 $\mu K^o$.

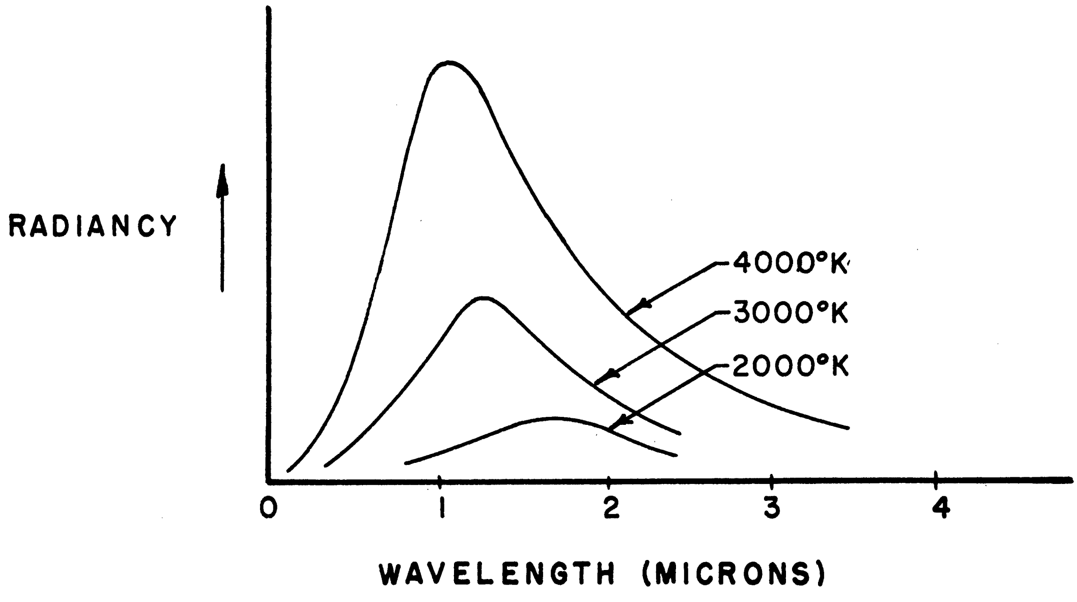
Spectral distribution functions were derived by Wien and Rayleigh, both of which were in error in certain wavelength regions. Max Planck, in 1900, arrived at an expression which combined the better parts of the Wien and Rayleigh functions. His investigations led him to the revolutionary theory of quanta.

Non-black bodies (i.e., all real bodies) are characterized by



TYPICAL RADIATION vs. WAVELENGTH DISTRIBUTION

FIG. 1



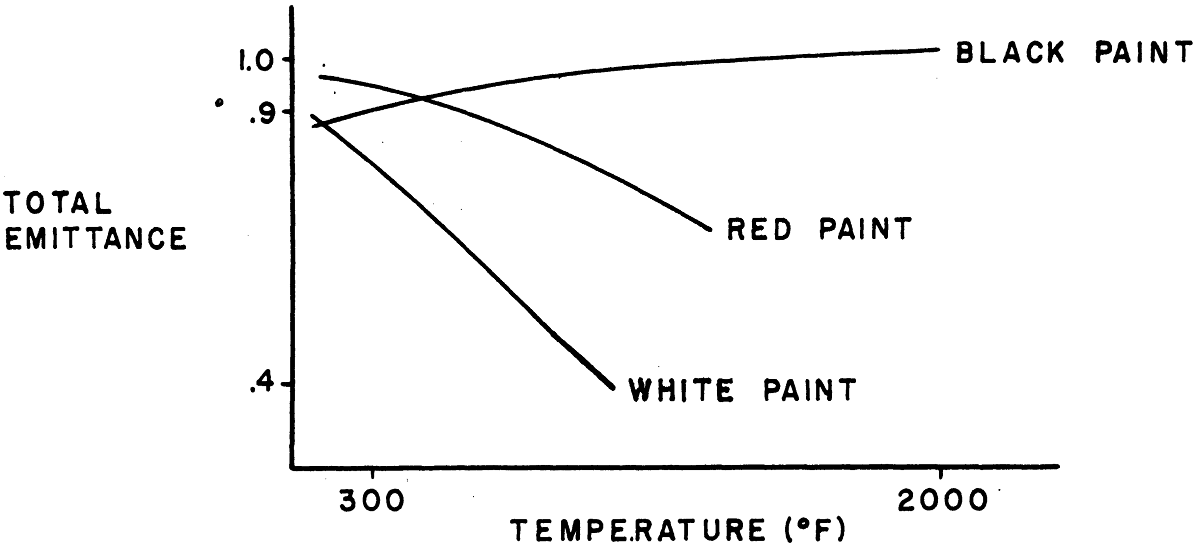
SPECTRAL DISTRIBUTION WITH TEMPERATURE AS A PARAMETER

FIG. 2

three things: (1) their ability to reflect, $\rho$; (2) their ability to transmit, $\tau$; and (3) their ability to absorb, $\alpha$. We have then

$$\rho + \alpha + \tau = 1$$

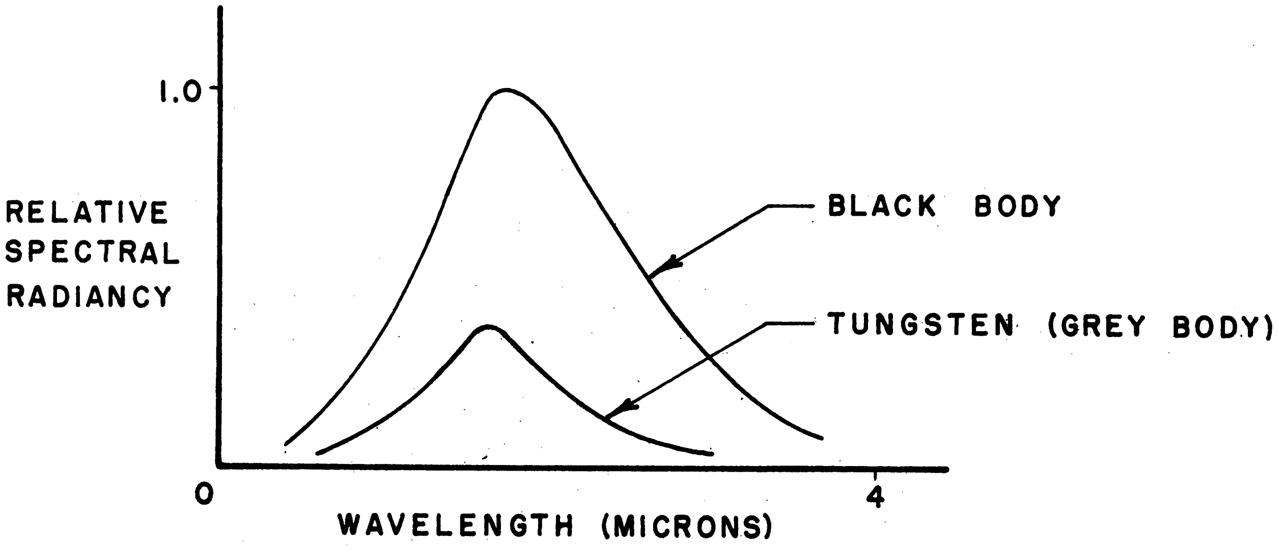
as a consequence that the body can only reflect, absorb, or transmit radiant energy incident on it. It is important, in the case of the emissivity or absorbtivity, not to confuse the word "black", meaning highly absorbant, with the visible color black. The colors, as we know them, are representations of emission and reflection in the visible range. As the set of curves in Fig. 3 show, this relationship does not hold for other wavelengths. Note that red paint is "blacker" in the emissivity sense than black paint at 200° F.



EMITTANCE vs. TEMPERATURE
FOR SEVERAL PAINTS

FIG. 3

Surface conditions, such as tarnish, greatly effect the emittance. The curves in Fig. 4 show the spectral distribution of tungsten and a black body at 2450° K. The tungsten curve lies everywhere below the black body curve. The areas under the curves (extended to $\lambda = \infty$) have a ratio of 0.3 which is the emissivity of tungsten at 2450° K. The term "grey body" is used for objects having a spectrum similiar to an ideal black body but with an emissivity less than one.



SPECTRAL DISTRIBUTION OF BLACK AND GREY BODIES

FIG. 4

A rather complete list of units and definitions are given in reference 1. A few of the more descriptive are given below.

Radiant energy, U, joules

Radiant flux, $\Phi = \frac{dU}{dt}$, watts

Introducing the solid angle $\omega$ we have

Radiant intensity, J, $J = \frac{d\varphi}{d\omega}$, $\frac{\text{watts}}{\text{steradian}}$

The infrared field is broken up into logical divisions in what follows. The first topics to be considered are the transmitters and transmission medium - targets and backgrounds. Following this we take up the receivers - detectors and optics.

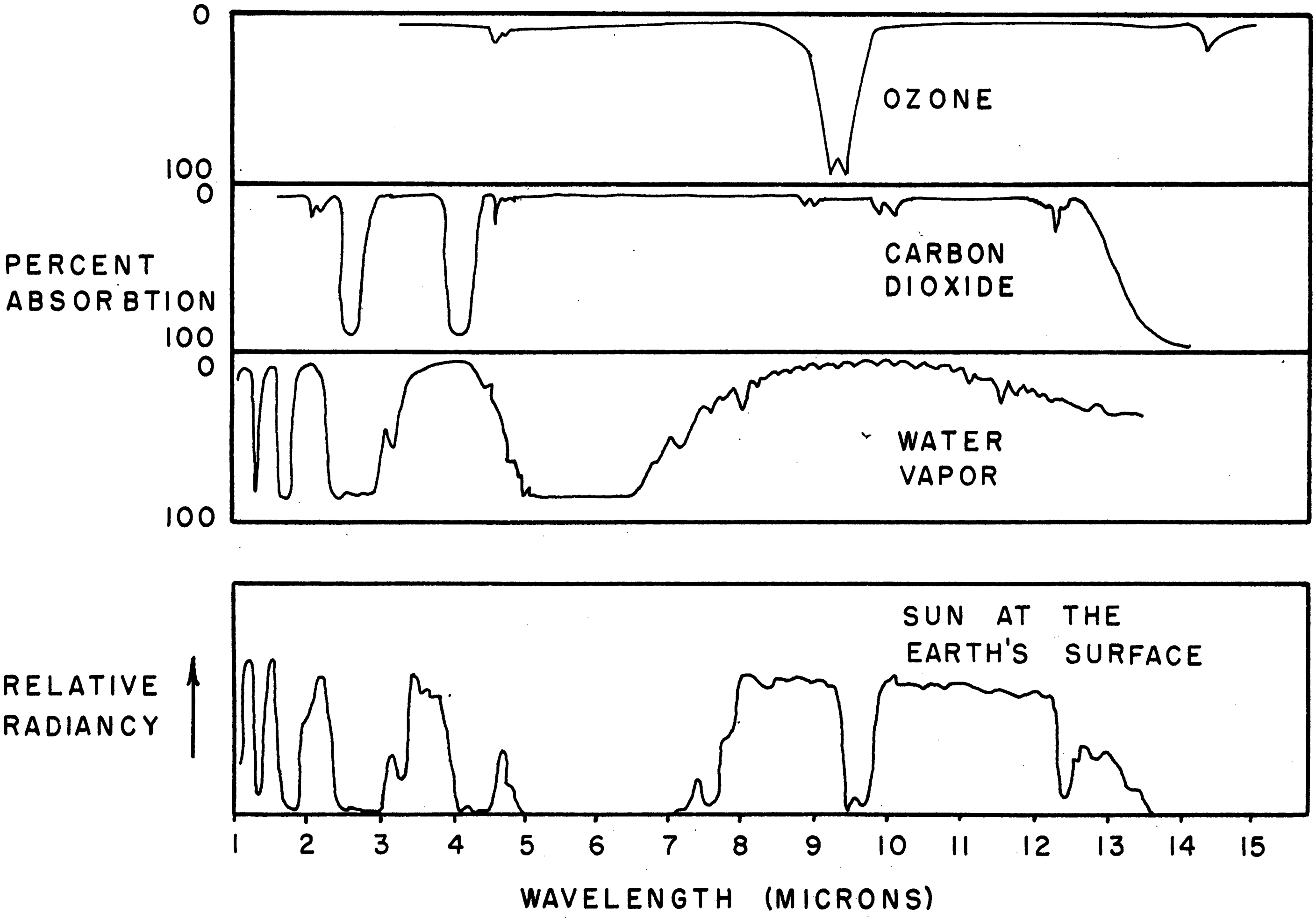
## III TARGETS AND BACKGROUNDS

This aspect of the infrared problem is concerned with the objects which are radiating in the infrared part of the spectrum. As discussed in Section II, all bodies between absolute zero and about 4000 degrees centigrade radiate in the infrared almost exclusively. It was noted above that if these bodies were "black", and at a constant uniform temperature, their spectral distribution would be known both in wavelength and amplitude. Neither of these conditions are met, however, in actual practice. Both the emissivity and the temperature are variables over the surface of any particular object. The emissivity is a function of both surface and wavelength. The temperature is a function of the shape and external cooling and heating effects. While some objects radiate with a distribution which is nearly that of a black body, many do not, and many more have not been investigated as to their spectral distribution.

A great amount of the recent experimental work which has been done on this subject has been directly connected with military applications. Data have been taken on the spectral distribution of many promising military targets. These data are available to people with a "need to know". Two types of radiation (or absorption) are noted in the data. The first is the more or less continuous spectral curves which may closely approximate a black body. The second type is associated with substances which emit strongly in certain bands of wavelength. The field of infrared spectroscopy is concerned with these distributions.

Aside from the radiation spectra and patterns from particular objects such as tanks, airplanes, factories, etc., much work has been done on a study of the characteristics of the earth and its atmosphere in the infrared region. Most of the applications presently envisioned for infrared are limited to some extent by these backgrounds. The absorption, scattering and radiation of the atmosphere, the radiation and its fluctuations from the earth, the reflections from the earth, and the radiation from celestial bodies have all been studied. Because of our natural interest in solar radiation (the sun is at about $6000^{o}$ K - above the infrared region with its peak) much study has been exerted on its radiation at surface level and at altitude.

The spectra of the sun, in the infrared region, is affected by the absorption by the various gasses which make up our atmosphere. The curves in Fig. 5 show the relative absorptions of several of the more important atmospheric gasses and the resulting solar spectrum at the earth's surface. Studies have been conducted, with altitude as a parameter, revealing the composition of the atmosphere as a function of altitude. It should be noted that the same absorption which affects the solar radiation also affects any other infrared radiation passing through the atmosphere.



ATMOSPHERIC GAS ABSORBTION AND THE RESULTING SOLAR SPECTRUM (OHIO STATE UNIV.)

FIG. 5

Relationships are available (called "range equations") which give the power available for detection at a given distance from a source with an intervening absorbing medium (Ref. 2). These equations take into account the emissivity of the body to be detected, the wavelength, the depth of absorbing medium and its nature, and the areas involved.

Scattering may present a limitation in some cases. In the atmosphere, scattering is mainly accomplished by three mechanisms.

1. Scattering by air molecules
2. Scattering by water droplets
3. Scattering by dust particles

Scattering by the air molecules is Rayleigh scattering, being proportional to $\lambda^{-4}$. Scattering by larger particles (water and dust) may be explained by the Rayleigh theory until the ratio of radius to $\lambda$ reaches about 0.13. Curves of scattering coefficient versus particle size divided by $\lambda$ are available. Natural fog presents radii of from one to 10 microns. In general, the longer wavelengths are less affected by scattering and thus an advantage of infrared over the visible wavelengths is obtained. Haze, composed of water and dust, scatters infrared much less than it does the visible wavelengths. Cirrus clouds, ice, are virtually transparent at high altitudes.

The general problem of radiation about the earth can be divided into two fairly distinct parts; i.e., radiation which occurs during the day and that which is of significance at night. These can be further divided into azimuth ranges, looking up or down from a point above the earth.

(1) Daytime - above the horizon. The large contributers are primary and secondary scattering of direct and reflected sunlight, and the emission by water vapor in the atmosphere.

(2) Daytime - below the horizon. The principle contributers are reflected solar radiation, emission from the earth, and emission from the atmosphere. Scattering effects below the horizon are negligible. The earth surface reflects, as a whole, 20% of the energy impinging on it. This is in general not proportional to wavelength in the regions of interest here. Tests conducted during World War II showed changes in background radiation over land by a factor of two to three. We thus have a direct analogy to "radar ground clutter" when the detector is swept over the daylight earth. The mean level is about 288° K which is very close to the

night value.

Another way to discuss the daylight background radiation is to divide the spectrum up into wavelength regions. In the one to two micron region scattered radiation predominates in the upper hemisphere and reflected radiation predominates in the lower hemisphere. Scattered radiation drops off sharply as the horizon is reached due to the increase of path length and the water vapor absorption. The radiation at two microns is less than that at one micron by a factor of 100.

At 2.5 microns solar radiation decreases and absorption increases. Emission from the earth and atmosphere assume a larger role. In the upper hemisphere the atmospheric emission is about 2/3 of the total. In the lower hemisphere emission from the atmosphere predominates over emission from the earth by about 5 to 1.

At 3.5 microns most of the emission is from the atmosphere. Water vapor absorption is high and the solar radiation has almost disappeared. At 10 microns the emission from the atmosphere and earth are about equal in the lower hemisphere.

Time and space fluctuations about the mean values are extremely important and are not, in general, amenable to theoretical approaches. Experimental data is necessary to properly evaluate these distributions.

In attempting to detect targets against the background the typical technique used is to identify targets by the high rate of change of the detected signal. It is generally assumed, or at least hoped, that the target will present a sharp boundary in radiation intensity, or wavelength, against the background. Cloud edges and similar obstructions can seriously affect this assumption. Fluctuations may, in general, be due to two causes. These are: (1) fluctuations due to actual time changes in background radiation in a certain direction; or (2) fluctuations caused by scanning across different parts of the background having differing brightness.

At night air and earth components remain relatively unchanged. Scattered and reflected sunlight disappears completely and is replaced by night sky airglow, the aurora, starlight, etc. Night sky airglow is down by a factor of $10^4$ to $10^6$ from scattered and reflected sunlight. At small wavelengths (0 to 4 microns) the sky background will consist essentially of emission from the atmosphere. Day sky background will be diminished by, at most, a factor of $10^2$ at night. Total radiation (all wavelengths) will change very little from day to night due to the importance of the earth's emission at the higher wavelengths. At high altitude, above the effective water vapor atmosphere, the mean level is just the night sky airglow. This is down by a factor of $10^6$ over the day. The continuous night background is often omitted in calculations, particularly where small wavelengths are to be detected. Depending on the circumstances, stars may be an effective target and must be considered.

A fair collection of data have been taken on the radiation distribution, in wavelength and space, about aircraft (see Ref.'s 2 and 3). At Mach 1, for instance, skin temperature becomes a cause of significant radiation. Above 30,000 feet altitude the sun produces an appreciable heating effect. The engines and their exhausts are, however, the main sources of radiant energy and distributions about them have been measured.

Much work remains to be done in the general area of targets and backgrounds, especially with a view toward military applications. Some topics of interest which have not been sufficiently investigated are listed below.

1. Atmospheric transmission
    a. from 10,000 feet up
    b. other than horizontal paths
2. Discontinuities in sky background
3. Celestial objects
4. Night sky, clouds
5. General ground backgrounds
6. General study and unification of data on targets including missiles and jets in flight.

## IV DETECTORS

Having established the existance of infrared radiation from almost all objects in our environment we now turn to the methods of sensing or detecting this radiation. We are all aware of the ability of the human body to detect, in a very qualitative sense, the presence of infrared radiation. Other devices of a much simpler and more quantitative nature have been devised for this purpose. The basic idea, as in any detection scheme, is to observe some change which gives an indication, with some reasonable degree of success, of an event. Furthermore, it is often desirable to achieve a quantitative measure of the radiation intercepted with regard to its magnitude and/or wavelength. Theoretically, any device which registers a change in its latent state corresponding to a change in the impinging infrared radiation is capable of being used as a detector. As would be reasonable to assume, however, some devices are much better at this job than others. The mechanism of detection is limited by the ability of the detector to distinguish the desired causality from other existant, but, in general, unwanted causalities. Thus, we are led to the subject of noise with its sometimes misused signal-to-noise ratios.

Certain devices, or classes of devices, have been discovered which yield adequate indications of the existance and amounts of infrared radiation in the presence of the other unwanted signals. In most cases these devices have been perfected, either through experiment or theory, to have an optimum detection ability; however this is defined for the situation.

Two basic classes of infrared radiation detectors are currently in use. These classes are distinguished by their wavelength response. One class, the non-selective detectors, are those which exhibit little dependence of their detection efficiency on wavelength. These detectors are known as total radiation detectors since they measure the total radiation impingent on them regardless of its spectral distribution. The other class of detectors are selective with respect to wavelength. The radio frequency analog is, of course, the contrast between wide open and narrow-band receivers.

The non-selective detectors are, in general, those in which the radiation power is converted into a readable signal by means of a change in the temperature of some sensitive element. These detectors are known as thermal detectors. Typical detectors belonging to this class are the thermocouple, thermopile, radiometer, bolometer, thermistor, and the Golay pneumatic detector. The selective detectors include a wide variety of devices including the human eye, image tubes, the photographic plate and photoelectric cells. Photoconductive cells occupy at present a major role in the field. These detectors are known as quantum detectors, their mode of operation being the detection of selected energy quanta.

A brief discription of a few detectors in each class is given below. A more complete treatment is contained in the references.

A radiation thermocouple consists of a pair of thermoelectric junctions with blackened radiation receivers attached to one or both junctions. A thermopile is a number of such thermocouples connected in series. A galvanometer or potentiometer is frequently used to measure the thermal emf's developed. Bismuth and silver are commonly used metals. Thermopiles may have a common blackened body to which each "hot" junction is attached.

A radiation bolometer consists of a ribbon of electrically conducting material which has a conduction dependent on the temperature of the ribbon. The ribbon is thin and usually blackened on one side to receive the radiation. The conductivity change may be detected by a bridge technique or by observing the voltage change when a constant current is passed through the ribbon. A thermistor utilizes a semiconductor which has a high temperature coefficient of resistivity.

A thermionic detector is a diode in which the cathode is heated by the radiation. The tube is operated in a temperature-limited condition and so all of the emitted electrons are collected by the anode. The cathode is designed to have a very small thermal capacity per unit area. Although reported promising, this type of detector has had little application.

The Golay pneumatic heat detector consists of a small, gas-filled chamber with an infrared transmitting window. Inside the chamber is a metallized membrane of very low thermal capacity to absorb the incident radiation. The resistance of this membrane, which is in effect a broad band radio antenna, is adjusted to approximately 265 ohms (.707 times the impedance of free space) for maximum radiation absorption. A short duct connects the chamber to a flexable membrane which is an optical reflector. This type of detector is the only existing heat detector operating close to the limit set by photon noise.

The second class of detector, the selective detector, is represented by a large assortment of devices. Of principle interest today are the semiconductor materials exhibiting photoconductivity and photoemissivity. The fundamental difference between the photoemissive cell and the photoconductive cell is that in the former the absorbed quanta have sufficient energy to liberate electrons completely so that they may be collected by a suitable anode. Photoconductive cells do not emit electrons but absorb sufficient energy from the quanta to enable the electrons to change from a bound state, where they are incapable of contributing to conductivity, to a free state where they are capable of carrying a current. Photoconductors are the more prevalent detectors in use. The selectivity in wavelength of photoconductors is due to the minimum quantum energy required to free the electrons. Quantum energy is related to wavelength by the equation $E = \frac{hc}{\lambda}$, where h is Plancks constant and c is the velocity of light. There exists, therefore, a fairly well defined maximum wavelength beyond which the sensitivity of the photoconductor falls off rapidly.

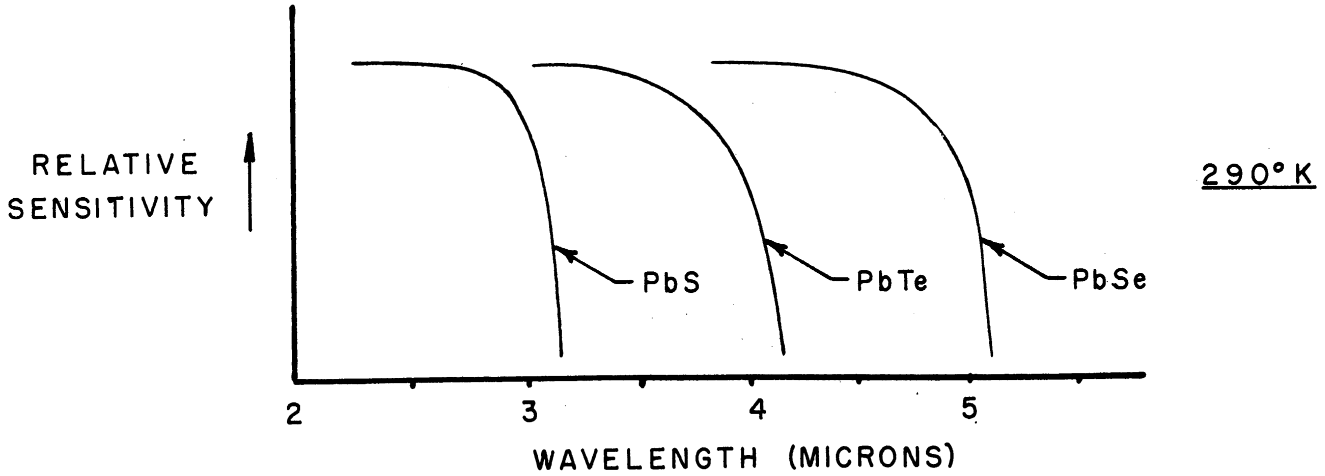
A fundamental difference which exists between quantum and heat detectors is their response time. In the heat, or total radiation, detector the sensitive element has to warm up after the radiation is applied. Fast thermal detectors have a response time in the order of a fraction of a second. Typical response times for quantum detectors are one to one hundred microseconds.

Of the many semi-conductor materials which have been studied as photoconductors (all semi-conductors and insulators are photoconductors) several have received particularly concentrated attention. The lead salts are perhaps the most used detectors today. Lead sulfide has been studied extensively. Lead selenide and lead telluride are receiving an increasing amount of attention. Other detector materials include germanium, doped and undoped, n and p type; various intermetallic compounds, and the III - V compounds composed of elements from the third and fifth columns of the periodic table.

Curves showing the relative responses of PbSe, and PbTe are shown in Fig. 6. The curves extend, in general, over a rather wide range of wavelengths below the cut-off. The challenge has been at the longer wavelengths where, up until very recently, only thermal detectors were available. These curves are for a constant temperature of the detector. As might be expected the response shifts with temperature. Figure 7 shows the spectral sensitivity of PbSe with temperature as a parameter. PbS and PbTe act similiarly. Sensitivity comparisons are intended to be qualitative only.

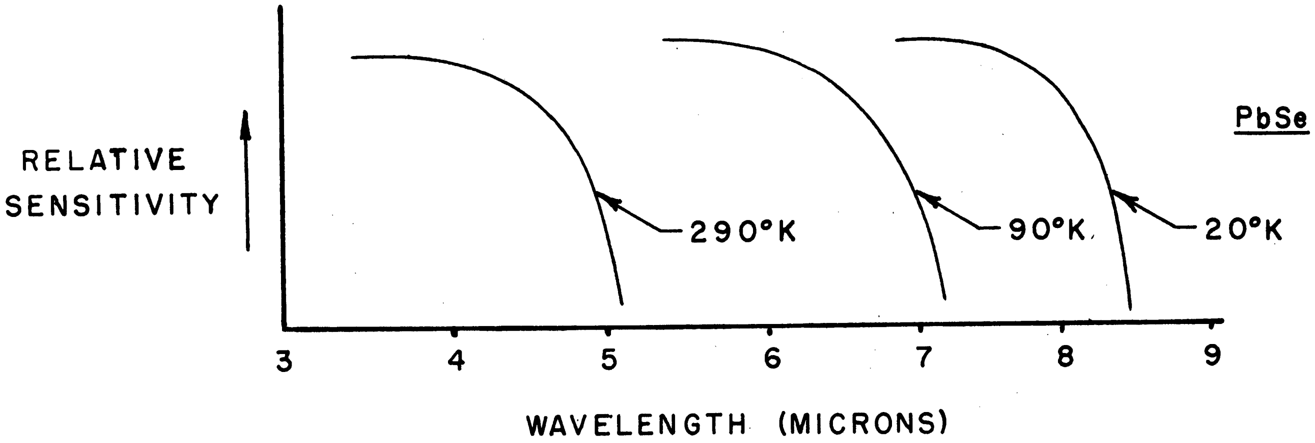
The signal frequency response of these cells has not been investigated in great detail. Evaporated PbS cells are down to one-half their low frequency response at about 3000 cps. Chemical layers of PbS may drop off at 300 cps. PbTe and PbSe are much higher and have not been measured adequately. Values to $10^5$ cps should be possible.

No mention of the noise restrictions on the various detectors will be made in this report. Some excellent articles are available which cover



WAVELENGTH SENSITIVITIES OF THREE PHOTOCONDUCTORS

FIG. 6



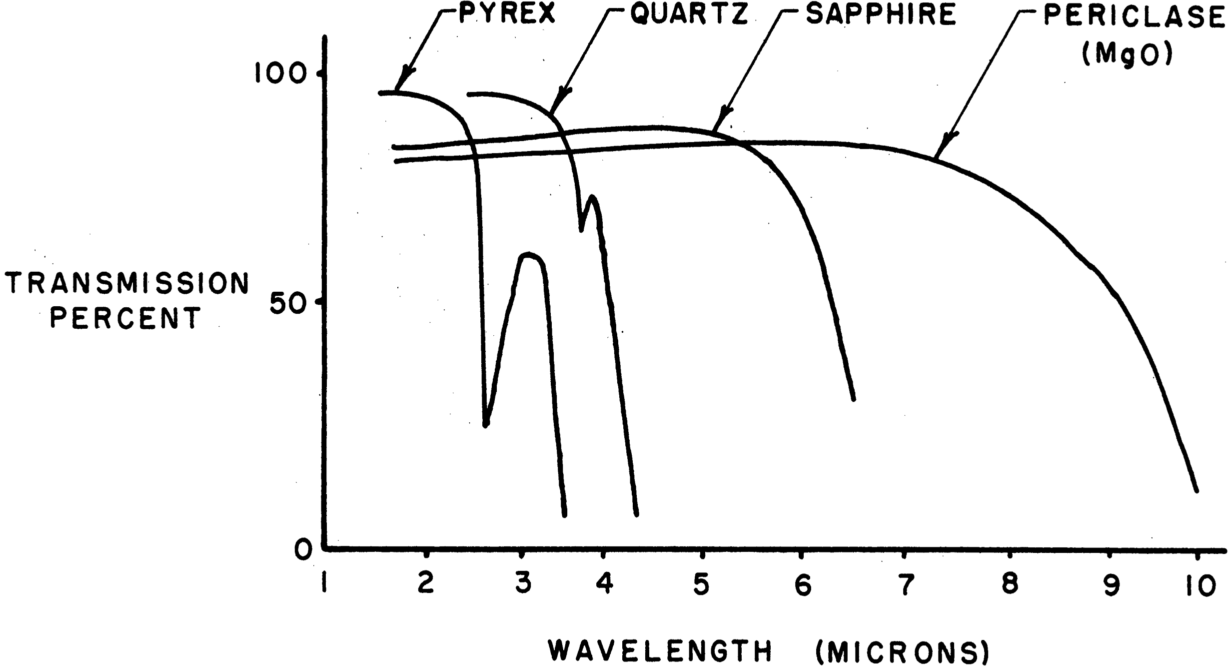
WAVELENGTH SENSITIVITY OF A PHOTOCONDUCTOR WITH TEMPERATURE AS A PARAMETER

FIG. 7

this field well and little is to be gained by a summary here ( Ref. 4). Suffice it to say that "noise", properly defined, is the fundamental limitation on all detector operation.

An integral part of many detection systems is an optical device. While some detectors operate with direct impingment of the radiant energy, many others have, for various reasons, an optical system. These optical systems operate, and are used, in a manner analogous to optical systems in the visible spectrum range with which we are all more or less familiar. A discussion of the principles and mode of operation of optics will not be attempted here. Optical systems in the infrared perform as window materials, lenses, reflectors, and filters (both lens and reflector types).

The most significant problem in the investigation of adequate transmitting materials has been the long wavelength cutoff. Most researchers in the field today are attempting to devise window materials with the capability of transmitting longer wavelengths. Very little theory has been devised as an aid in this task. A general dependance of cutoff on crystal spacing has been noted. Some typical materials are shown in the curves in Fig. 8, showing their percent transmissions as a function of wavelength. Many materials which have satisfactory transmission properties are extremely poor in other basic physical properties such as water solubility, heat resistance, strength, etc. Others are extremely expensive and/or difficult to manufacture.



TRANSMITTIVITY OF FOUR MATERIALS

FIG. 8

A list of some of the more interesting and newly devised optical materials is given in Table 1 showing some of their more important physical properties.

| | KRS-5 | $A_g$Cl | $As_2S_3$ | $Al_2O_3$ | Si | $M_g$O | $SiO_2$ |
|---|---|---|---|---|---|---|---|
| Transmission Limit Microns | 40 | 30 | 12 | 5.3 | 7.5 | 7 | 4 |
| Index of Refraction | 2.4 | 2 | 2.4 | 1.7 | 3.4 | 1.7 | 1.45 |
| Hardness | 40 | 9.5 | 100 | 1370 | $\sim$500 | 690 | 470 |
| Solubility ($H_2O$) | 0.05 | 1.5x$10^{-4}$ | 5.2x$10^{-5}$ | 9.8x$10^{-5}$ | — | 1.2x$10^{-5}$ | $\sim$0 |
| Melting Point (°C.) | 415 | 458 | 210 | 2030 | 1420 | 2800 | 1700 |
| Linear Expansion Coeff. X$10^{-6}$/C° | 58 | 30 | 25 | 6 | 2.4 | 13 | 0.5 |
| Thermal Cond. Coeff. | 22 | 26 | 4 | 6 | 84 | 8 | 0.28 |
| Homogeniety | good? | poor | good | — | — | ? | excel. |

AgCl - Cerargyrite
$As_2S_3$ - Orpiment
$Al_2O_3$ - Corundum, Ruby, Sapphire
MgO - Periclase
$SiO_2$ - Quartz

TABLE 1 SOME INFRARED OPTICAL MATERIALS
(from University of Michigan Willow Run Laboratory
Infra-Red Group)

Filters are commonly built up with either multiple or single layers using reflection or absorption. Aside from using materials which have natural absorption in certain desired bands, filters can be built up using 1/4 and 1/2 wavelength thick plates in various combinations. Filters can be constructed by this means which give response curves closely approximating, qualitatively, those typically used in electrical networks. A "Tschebyscheff" type of bandpass filter can be so constructed.

Optical devices can provide either a gain or an attenuation in a given system depending on their use.

# V SUMMARY

An introduction has been given to some of the fundamental physical concepts and equations in the infrared region of the electromagnetic spectrum. A division has been made between the transmitters and transmission media, targets and backgrounds, and the receiving devices including detectors and optics. Some basic aspects of infrared emitters and the transmission media have been noted in an attempt to give some insight into the relative prevalance of infrared radiation in our environment. The common types of detectors have been listed with a brief description of the operating mode of each. Some common optical materials have been given along with their more important physical properties.

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