

Infrared Luminescence of Minerals

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Infrared Luminescence of Minerals

By DAVID F. BARNES

EXPERIMENTAL AND THEORETICAL GEOPHYSICS

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*A study of the abundance and
causes of infrared luminescence
of minerals*



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FRED A. SEATON, *Secretary*

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Thomas B. Nolan, *Director*

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EXPERIMENTAL AND THEORETICAL GEOPHYSICS

INFRARED LUMINESCENCE OF MINERALS

By DAVID F. BARNES

ABSTRACT

Infrared luminescence is a phenomenon similar to fluorescence under ultraviolet light except that the emission occurs in the infrared rather than the visible part of the spectrum. This infrared luminescence is generally most efficiently excited by visible light from high-energy incandescent lamps, but violet and ultraviolet excitation are effective for a few minerals.

Infrared luminescence can be viewed through an infrared image tube of the type used in the "snooperscope." The entire study collection of the U. S. National Museum has been examined with an image tube and optical system of a snooperscope to detect the infrared luminescence of minerals. Infrared luminescence was found in about 1,500 specimens representing some 75 distinct mineral species. Filters were used to determine the approximate wavelengths of emission and excitation.

Chromium-activated minerals like corundum, beryl, spinel, jadeite, and kyanite show very strong infrared luminescence. Cadmium causes the universal luminescence of its sulfide, greenockite. The rare earths are responsible for the long-wavelength emissions of many minerals including scheelite, fluorite, apatite, feldspar, and amphibole.

INTRODUCTION

When some mineral specimens are illuminated by an ultraviolet lamp in an otherwise dark room, they glow with colors that are often far more brilliant than those of the same specimens in bright sunlight. This well-known mineral fluorescence involves the absorption of invisible light at the short-wavelength or ultraviolet end of the spectrum and the simultaneous emission of this energy as visible light of longer wavelength. Infrared luminescence is a similar phenomenon in which a mineral absorbs visible light and emits the energy as invisible light at the long-wavelength or infrared end of the spectrum. Stokes formulated the fundamental law of luminescence which states that the wavelength of the fluorescent light is longer than the wavelength of the exciting radiation. Infrared luminescence might thus result from either visible or ultraviolet excitation, but experiments show that in most cases the strongest emissions result from visible light.

The term "luminescence" includes the emission of light resulting from all processes except incandescence. "Fluorescence" is the emission of light at the same time as excitation, and "phosphorescence" is the emission of light following excitation. The term "fluorescence" is, however, frequently associated with emissions excited only by ultraviolet light; therefore the use of the general term "luminescence" seems preferable for infrared emission that is most effectively excited by visible light.

Infrared luminescence has already been observed photographically by Pauli (1911), Servigne (1938 and 1939), Weyl (1942), Lashkarev and Kossonogova (1946), Dh  r   and Biermacher (1936), and others, but the lack of a simple method of observation made a survey of many minerals impractical. However, the invention of the infrared image tube (Holst and others, 1934) and its further development during the last war made possible the rapid observation of infrared phenomena with wavelength shorter than 12,000 angstroms. Bailly and Holke (1944) following an idea of Malmquist (1945) used infrared radiation in studying the optical properties of minerals opaque to visible light, and adapted the infrared image tube to serve as an ocular for the petrographic microscope in the manner suggested by Zworykin and Morton (1936).

PURPOSE AND SCOPE OF INVESTIGATION

This report describes the use of the infrared image tube in an examination of the long-wavelength luminescence of minerals. Nearly 200,000 specimens comprising the study collection of the U. S. National Museum have been observed, and infrared luminescence was found in approximately 1,500 specimens representing some 75 distinct mineral species. The investigation determined which minerals show infrared luminescence, where these luminescent specimens are found, and the approximate wavelengths of emission and excitation. The work was divided into two main parts: first, a thorough, piece-by-piece examination of minerals for which luminescence had been previously reported—the group in which almost all infrared luminescence was found; and second, a scanning of all other specimens in the collection with subsequent piece-by-piece examination of those specimens that showed infrared luminescence.

ACKNOWLEDGMENTS

The author is indebted to many who have helped in the work. The project resulted from an idea of H. C. Spicer, of the U. S.

Geological Survey, who supervised the work. Members of the staff of the National Museum, W. F. Foshag, George Switzer, E. P. Henderson, and J. H. Benn, kindly made the Museum facilities available and gave frequent assistance in the identification of minerals. D. J. Looft and Jerome Laufler, of the Engineer Laboratory at Fort Belvoir, Va., assisted with the instruments. K. J. Murata and Michael Fleischer of the Geological Survey gave frequent and valuable advice and Elizabeth King helped in the preparation of the tables.

EQUIPMENT AND METHODS OF OBSERVATION

THE SNOOPERSCOPE

The telescope of a U. S. Army Model M-1 snooperscope was used for all infrared observations. Similar equipment is now manufactured for scientific research or is available on the surplus market. The snooperscope has an objective lens that focuses the primary image on the cathode of a 1P25 tube (Morton and Flory, 1946). The cathode is a silver-cesium oxide-cesium film, which, under infrared excitation, emits electrons which are then focused by a series of high-voltage electric fields on a zinc silicate phosphor screen showing a green luminescence under electron bombardment. The resulting green image is viewed through an eyepiece.

The lenses in the snooperscope telescope are designed to focus on an object between 4 feet and infinity, but for mineral observations this range was reduced to approximately 9 inches with a 3 diopter portrait attachment. The objective lens was also covered with a filter to limit the sensitivity to the infrared band, because the spectral range of the 1P25 tube extends into the visible part of the spectrum.

For nighttime military operations the snooperscope has an infrared spotlight that illuminates the object, but for studying mineral luminescence a broad range of exciting light from ultraviolet to infrared is required. Accordingly the infrared spotlight was discarded, and the specimens were either scanned with a unit having one high-intensity, broad-spectral-range exciting lamp, or they were examined in a viewing box in which a variety of wide- and narrow-band excitation lamps were used.

The viewing box was built first and was used for the examination of all mineral varieties that were mentioned in the literature as luminescent. The viewing box enabled the observer to estimate the approximate wavelength of infrared emission and to evaluate the relative effectiveness of various types of excitation. This detailed examination of each specimen was, however, very slow—

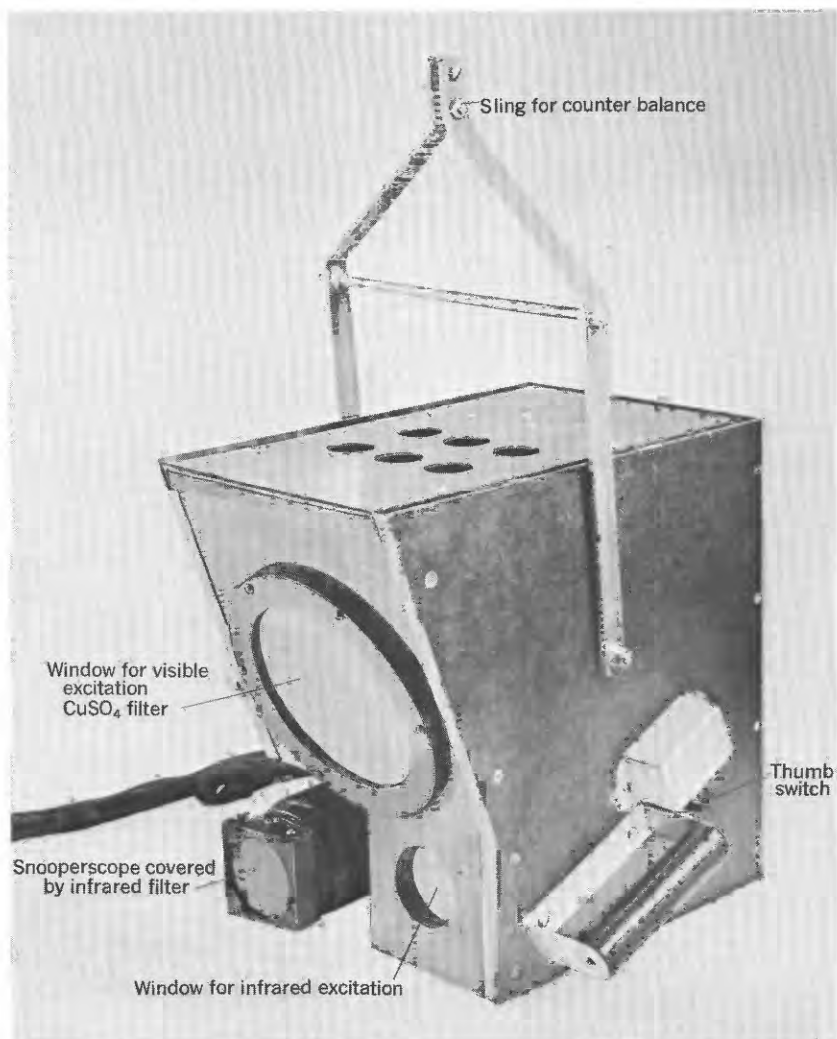
several months were required for the examination of the luminescent minerals alone, a mere quarter of the entire collection. To complete the project in a reasonable time a scanning instrument had to be built for the observation of the remaining three-fourths of the collection. As this scanning instrument was both simpler and more efficient it will be discussed first.

INFRARED LUMINESCENCE SCANNER

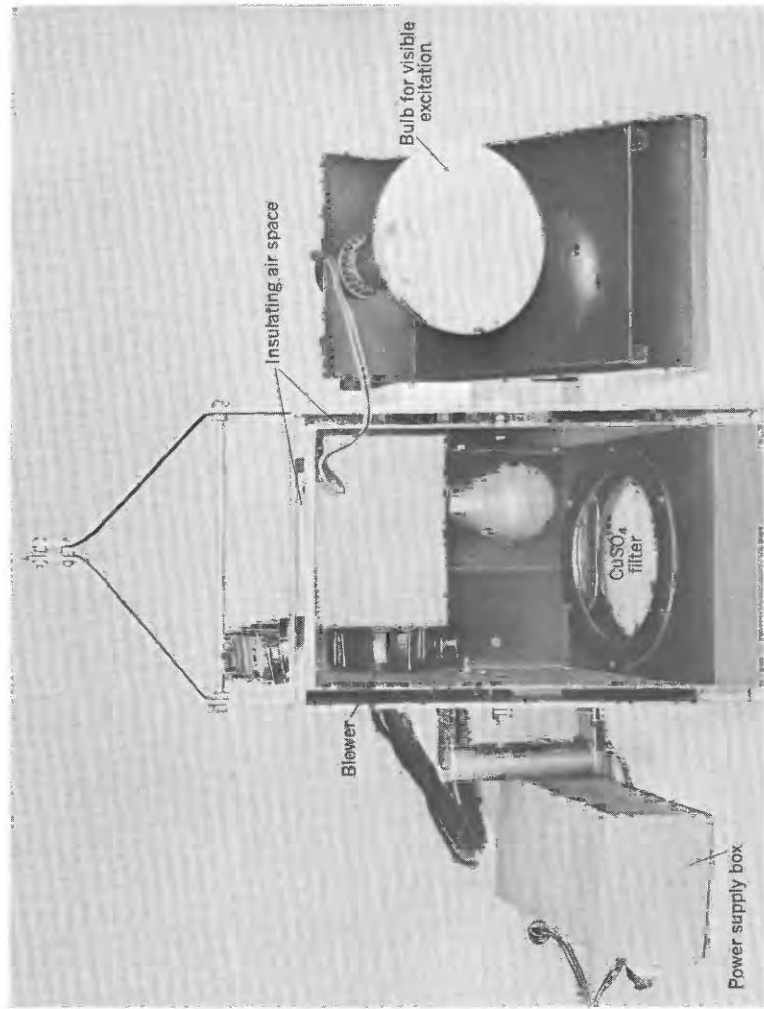
The preliminary examination of luminescent minerals showed that visible light would excite all types of infrared luminescence, and that a broad range of visible light was by far the most effective exciting source. Thus an instrument could be built capable of detecting any type of infrared luminescence in a single observation, provided a sufficiently powerful incandescent lamp was used.

The instrument built by the Geological Survey is shown on plates 4 and 5. A 500-watt photospot was used as the exciting source, but like all incandescent lamps this bulb actually emitted more energy in the infrared than in the visible region. The reflection of this infrared light by the mineral specimen would be strong enough to mask even the strongest infrared luminescence. Accordingly it was necessary to cover the photospot with a filter that would pass only visible light. This enabled the observer to examine infrared luminescence under conditions essentially similar to those used for the study of ordinary mineral fluorescence, when visible light is eliminated by keeping the room dark and by filtering out all but ultraviolet exciting radiation. The filter found most effective for the study of infrared luminescence was a 5-percent CuSO_4 solution in a glass or lucite chamber three-quarters of an inch thick; such a filter transmits visible light very well and has a sharp cutoff between 5,500 and 6,500 angstroms. In the infrared scanner this filtering solution was contained in a 6-inch diameter chamber built into the front wall of the instrument.

However, no filter is perfect; the copper sulfate solution passed a little infrared light, and the infrared-transmitting filter in front of the snooperscope telescope did not eliminate all the visible light from the exciting source. Accordingly, nonluminescent minerals that were good reflectors appeared brighter than those which were poor reflectors, and it was difficult to distinguish strong reflection from weak luminescence. Therefore the scanner was provided with a much weaker second lamp covered with an infrared transmitting filter similar to that in front of the snooperscope telescope. A pushbutton switch turned on this infrared



INFRARED LUMINESCENCE SCANNER



INFRARED LUMINESCENCE SCANNER OPENED

light source and at the same time, turned off the photospot. It was thus possible for the observer to quickly estimate the long-wavelength-reflecting properties of the mineral specimen and to judge whether the brightness seen under the visible excitation resulted from reflection of the small amount of light "leaked" by the filters or from actual luminescence.

The two lamps generated considerable heat, so that the inside of the instrument had to be cooled by a small blower. Even with this blower operating, the case of the instrument became so hot that the observer's face and hands had to be protected by a second, outside wall of laminated plastic separated from the inner, aluminum walls by a $\frac{1}{4}$ -inch air space. The instrument was designed primarily for easy construction, and little emphasis was placed on lightness of weight. When completed it weighed about 15 pounds, light enough to be held in the hands for a short period but too heavy to be carried for a whole day. When used to examine the specimens in the high stacks of drawers that hold the study collection of the National Museum, the instrument was supported by a rope running through a pulley system to a counterweight. The observer could thus aim and focus the instrument with very little effort.

VIEWING BOX

With the scanner the observer could detect infrared luminescence and estimate its intensity, but with the viewing box he could learn many additional characteristics of this luminescence. Filters could be used to eliminate all but a narrow spectral band of excitation energy or to restrict the detection range to narrow bands. Thus the relative importance of various wavelengths of excitation and emission could be estimated.

The arrangement of apparatus in the viewing box is shown in figure 25. The box was constructed so that the specimen could be held in the observer's left hand, while his right hand was used to change filters and to turn on and off the excitation lamps, which were operated by pushbutton switches on the outside of the box.

The first excitation lamp was a 25-watt bulb with an infrared-transmitting filter that showed the degree of infrared reflection exhibited by the mineral. Like the similar bulb in the scanner this was used primarily to distinguish infrared luminescence from reflected light "leaked" by the filters.

The second excitation lamp was a 300-watt bulb in a 35-mm slide projector ventilated by a small fan. As the condensing-lens system alone provided adequate focusing of the light beam, the projection lenses were not used. A $\frac{3}{4}$ -inch-thick lucite cell con-

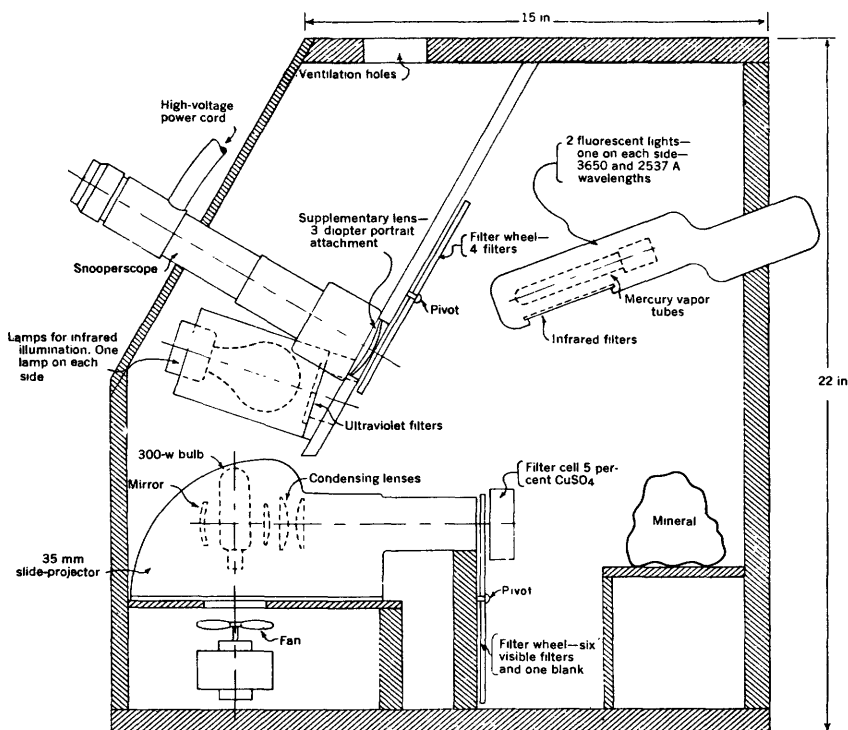


FIGURE 25.—Schematic diagram of infrared viewing box.

taining a 5-percent solution of CuSO_4 was placed in front of the projector to eliminate the infrared radiation generated by the bulb. This projector and its filter thus provided the same type of broad range visible excitation that was furnished by the photo-spot bulb in the infrared scanner. In the viewing box, however, this visible excitation could be separated into five narrower spectral bands by gelatine filters placed in front of the projector. Each filter passed a spectral band about 800 angstroms wide, and was mounted on a wheel, so that it could be rapidly shifted into position in front of the projector. Table 1 shows the color of light transmitted by each filter.

The third and fourth excitation lamps were two ultraviolet lamps with wavelengths of 3,650 Å and 2,537 Å. Unfortunately, both these lamps produced a moderate amount of infrared radiation, the reflection of which by the specimen tended to mask any actual infrared luminescence. Accordingly a lucite cell $\frac{1}{2}$ -inch thick and containing a 5-percent CuSO_4 solution was interposed during most of the experiments to absorb the infrared radiation

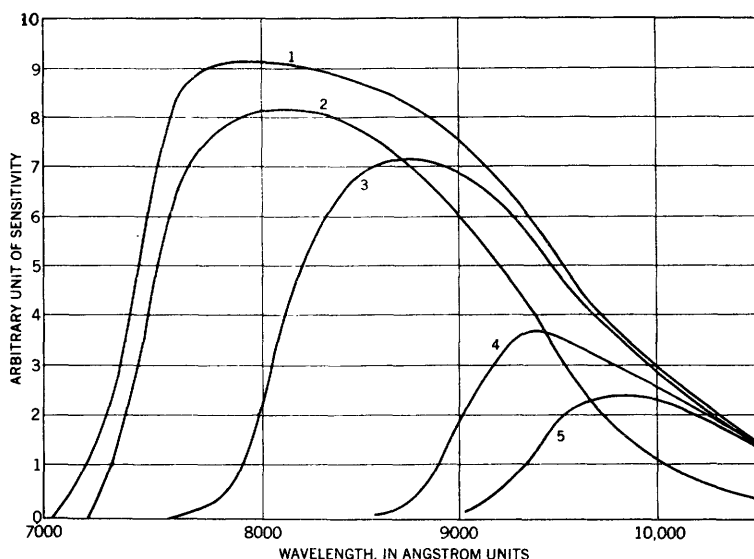
transmitted by the filter of the SL 3650 lamp. However, such solutions of copper sulfate, even in a quartz cell, absorb about 25 percent of the ultraviolet at 3,600 Å and nearly 100 percent at 2,500 Å. Consequently a liquid filter could not be used to eliminate the large amount of infrared emitted by the 2,537 Å source.

The observer estimated the intensity of the infrared luminescence excited through each of the six filters in front of the projector and by the two ultraviolet lamps. To use these observations to evaluate the relative effectiveness of various wavelengths of excitation it was essential to know at least approximately the amount of energy provided by each source. Unfortunately none of the available methods of illumination measurement is reliable over such a broad spectral range, and the excitation energies had to be calculated from the data available from manufacturers of the components of the illumination system. The methods used for these calculations are given in Moon (1936) and Skogland (1929). The results are given in figure 26*B*, which shows the spectral distribution of energy transmitted by each filter. The total energy transmitted, or the integral beneath each of the curves in figure 26*B* is shown in table 1. The energy produced by the two ultraviolet lamps is so small that it would not show on the graph, but it is given in the table. One can perhaps question the accuracy of some of the assumptions made in computing the energies recorded in table 1, but the relative values are probably at least as accurate as the visually judged measurements the table is intended to explain. Furthermore, the questionable assumptions affect only the relationship between the incandescent and the ultraviolet lamps; the relationships between the energies passed by each filter in front of the projector depend only on the color temperature of that bulb and on the individual filter characteristics, both of which are well known. The decrease in energy transmitted by the filters at the violet or short-wavelength end of the spectrum and the weakness of the ultraviolet lamps compared to even filtered parts of the projector's energy are clearly shown.

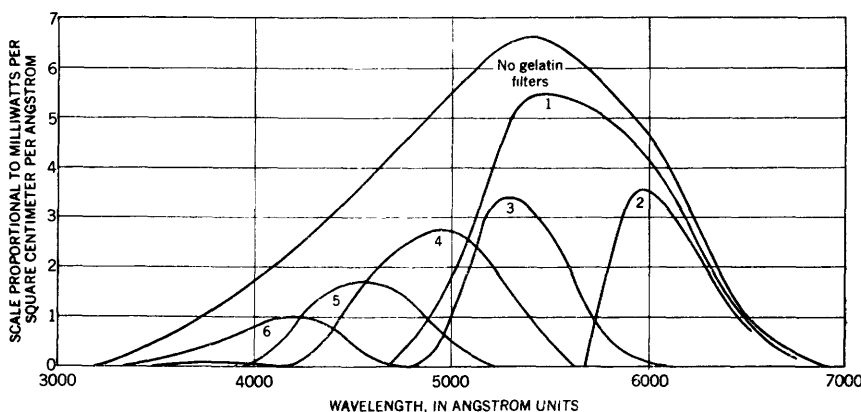
To obtain the approximate wavelength of the infrared emission, the spectral range of the viewing system could be varied by rotating a filter wheel mounted in front of the objective lens. This wheel held four filters, whose low wavelength cutoffs ranged from 7,000 to 9,300 Å. The spectral transmission curves of these filters were obtained from the manufacturers and were then applied to the spectral sensitivity curve for the 1P25 tube. The resulting sensitivity curves for the receiving unit are shown in figure 26*A*. These curves show that any luminescence with wavelength longer

than approximately 9,500 Å will give a very weak image regardless of its actual intensity.

Actually some evidence suggests that curve 1 in figure 26A should extend further into the visible part of the spectrum. First, many minerals give very different brightness values with filters 1 and 4, which contradicts the apparent closeness of their curves.



A. SPECTRAL CHARACTERISTICS OF THE INFRARED DETECTING UNIT WHEN COVERED WITH VARIOUS FILTERS



B. SPECTRAL CHARACTERISTICS OF THE 300-WATT INCANDESCENT LAMP WHEN COVERED BY COPPER SULFATE FILTER PLUS VARIOUS GELATIN FILTERS

FIGURE 26.—Spectral sensitivity of filters used in the viewing box.
Data obtained from manufacturers.

TABLE 1.—*Characteristics of filters used in excitation measurements*
 [Curves showing characteristics of filters 1-6 are shown on figure 26B]

Filter no.	Excitation bulb	Color	Wavelength range (angstroms)	Integrated energy milliwatts (per cm ²)	Energy \times wavelength
None	300-watt incandescent	Visible	3,500-6,600	117	62
1	do	Red-green	4,800-6,600	63	35
2	do	Red	5,700-6,600	20	12
3	do	Green	5,000-5,800	20	11
4	do	Blue	4,400-5,500	22	11
5	do	Blue-violet	4,200-5,000	12	6
6	do	Violet	3,800-4,500	7	3
8	Fluorescent tube	Ultraviolet	3,600	.2	.1
9	Hg-vapor tube	do	2,500	.3	.1

Second, many minerals known to give a strong emission just below 7,000 Å show brilliant images through filter 1, figure 26A. Third, the detection unit picks up a considerable amount of infrared radiation transmitted from the projection bulb even with the CuSO₄ filter in place, but according to figure 26A these curves do not overlap. Part of this infrared transmission is probably explained by the 0.5 percent transmission of the CuSO₄ filter at approximately 10,000 Å, but the fact that filters 2, 3, 4 greatly reduce the observed "leakage" suggests that most of it occurs at shorter wavelengths. Thus, although the exact position of curve 1 is unknown, it probably extends into the visible region, the border of which is generally placed between 7,000 and 7,500 Å. The actual limit of perception varies with the individual; many people have an extremely slight perception up to 10,000 Å or nearly to the point where the heat absorption of the skin becomes important (Griffin, Hubbard, and Wald, 1947).

INFRARED LUMINESCENCE OF MINERALS

CHARACTERISTICS OF INFRARED LUMINESCENCE

According to the quantum theory of matter, luminescence results from the transfer of electrons between the energy levels of an excited atom. The atom is excited when an electron is raised to a higher energy level by the absorption of light; one photon, or quantum light energy, can excite only one electron. The luminescent emission occurs when the excited electron returns to a lower energy level with the release of another photon of light energy. The frequency of the light absorbed or emitted is directly proportional to the energy of the photon; therefore the wavelength of the light is inversely proportional to the energy of the transfer. Thus ultraviolet light, which has a short wavelength and there-

fore a high energy, can, by Stokes law, excite either visible or infrared luminescence, which have lower energy because of their longer wavelength. Many factors affect the probabilities of the absorption and emission of energy and therefore affect the efficiency of the luminescence. The surroundings of the luminescent atom within the crystal structure are especially important. In many minerals the excitation energy is absorbed by one, perhaps nonluminescent, atom, and is then transferred to the luminescent atom, or in other minerals the light emitted from one atom is reabsorbed by another.

Luminescent minerals can be classified into three groups according to the relationship between the luminescent atom and the host mineral.

The first group contains minerals in which the fluorescent atom is an essential chemical component and in which the fluorescent element is included in the chemical formula. This group includes the fluorescent uranium and tungsten minerals, whose visible emission is caused by the uranyl (UO_2^{+2}) and tungstate (WO_4^{-2}) ions. Greenockite is the only infrared luminescent mineral that can definitely be assigned to this group. In the second group of minerals the luminescent atom is not an essential chemical component but does form a part of the crystal lattice. Such atoms are known as activators and are commonly present in extremely small quantities (of the order of one part in a million). Nevertheless these activators have a considerable affect on the properties of many minerals, and they often determine the characteristic colors of subvarieties. Thus, alexandrite and ruby are chrysoberyl and corundum with distinctive coloring caused by the chromium ion. Very strong and nearly universal infrared luminescence is found in some minerals of this type.

In minerals belonging to the second group, the activator is present in only a few specimens and does not affect the physical properties of the mineral. As the inclusion of the activator in many minerals is accidental, the luminescence of some of them is found only in a very small percentage of specimens. The luminescence of such minerals is subject to wide variations in emission wavelength, excitation spectrum, and place of occurrence. This type of luminescence is, however, exhibited by many varieties of minerals. Typical examples are the brilliant red luminescence of calcite from Franklin, N. J., and the important infrared luminescence caused in many minerals by rare-earth activators.

The third group includes minerals in which the fluorescent atom is not represented in the chemical formula and does not form a part of the crystal lattice. Such luminescence is totally unrelated

to the nature of the mineral, although it is commonly associated with specimens found in specific localities. The cause of the luminescence is an impurity which can sometimes be distinguished by eye or microscope, or which at other times is difficult to distinguish in any way from activators forming a part of the crystal lattice. Sulfur from Italy, fluorite from Clay Center, Ohio, and halite from Stazunia, Poland, owe both their visible and infrared luminescence to included organic matter and are thus examples of this third group of luminescent minerals.

It is often difficult to assign a luminescent mineral to any one of these three groups; the groups are thus difficult to use as an actual basis of classification, but they do show the large variety of possible luminescent systems. Almost all luminescence depends on the presence of a minute quantity of elements that are not essential chemical constituents of the mineral. Even the amount of these activators is critical, and overconcentration can by reabsorption quench the luminescence, as effectively as underconcentration can make it impossible. Furthermore, additional elements can either aid or quench the luminescence. For example, Schulman, Evans, Ginther, and Murata (1947) have shown that the brilliant red fluorescence of calcite under ultraviolet light requires a sensitizing impurity such as lead, but this sensitizing impurity may not be necessary for the rarer and less intense infrared luminescence of calcite. One specimen of agate in the National Museum collection showed the importance of impurities and previous history on mineral luminescence. The original agate specimen had been cut into six pieces, each of which was treated in a different way to show the color produced; only one piece showed infrared luminescence—that quenched in sulfuric acid and honey.

The transparency of a mineral specimen has a considerable influence on its luminescence because the activating atom is seldom on the exact surface of the specimen, and both the exciting and emitted light have to pass through at least a small thickness of the crystal. Many examples of the importance of transparency were found in the study of infrared luminescence. Fluorescent cuprite has never been recorded, but Lashkarev and Kossonogova (1946) reported an infrared luminescence from cuprous oxide synthesized in a blast furnace. Almost every cuprite specimen is dull and opaque and shows no luminescence. However, a very small, deep-red, and very clear crystal from Cornwall, England, showed a distinct, long-wavelength infrared emission—a discovery that confirms Lashkarev's work and demonstrates the importance of translucence in mineral luminescence. Likewise, sphalerite and wurtzite, which are the mineral forms of the often-studied phos-

phor, zinc sulfide, show infrared luminescence only in specimens that are not completely opaque. In many other minerals the infrared luminescence was limited to at least slightly transparent specimens.

All luminescent mineral specimens were tested for infrared phosphorescence, and none was detected. Many minerals, however, show prolonged visible phosphorescence after ultraviolet excitation. This failure to detect infrared phosphorescence can probably be ascribed to insufficient sensitivity of the snooperscope, but the observed absence may be real and not instrumental.

The results of the investigation of the infrared luminescence of minerals are presented largely in tabular form because of the many infrared luminescent specimens discovered and because of the great variation in the properties of this luminescence. All the infrared-luminescent mineral varieties are listed below according to their chemical composition and crystal structure. Minerals without silica are arranged according to Palache, Berman, and Frondel (1944 and 1951) and the silica minerals according to Strunz (1941). This system of classifying minerals is similar in its main categories to Garlick's system (1949, p. 48) for the classification of phosphors.

In tables 2-4, the minerals are arranged in alphabetical order (p. 100-155). Table 2 lists all the localities where infrared-luminescent mineral specimens were found. Table 3 indicates the prevalence of infrared luminescence for each mineral; it gives the percentages of specimens and localities in which infrared luminescence was found. Table 4 shows the characteristics of infrared luminescence found in some of the individual specimens examined. These have been selected as representative samples of the different types of luminescence shown by each mineral.

Infrared-luminescent minerals

MINERALS WITHOUT SILICA

Native elements	Oxides—Continued
Diamond	Senarmontite
Sulfur	Corundum (ruby, sapphire)
Selensulfur	Valentinite
Sulfides	Cervantite
Sphalerite	Stibiconite
Greenockite	Stibianite
Wurtzite	Brucite
Oxides	Hydrotalcite
Cuprite	Bauxite
Montroydite	Diaspore

Infrared-luminescent minerals—Continued

MINERALS WITHOUT SILICA—Continued

Oxides—Continued

Spinel
Chrysoberyl
Alexandrite

Halides

Halite
Marshite
Fluorite
Terlinguaite
Matlockite
Cryolithionite
Cryolite
Gearsutite
Chiolite
Creedite

Carbonates

Calcite (reichite, oolite, pisolite)
Manganocalcite
Cuprocalcite
Plumbocalcite
Magnesite (baidisserite)
Rhodochrosite
Smithsonite
Aragonite
Strontianite
Cerussite
Dolomite (guruhofite)
Tautoklin
Pirssonite
Gaylussite
Phosgenite
Hydrocerussite
Leadhillite

Borates

Borax
Probertite
Ulexite

Borates—Continued

Colemanite
Meyerhofferite
Howlite
Hambergite
Sussexite

Sulfates

Barite
Celestite
Anglesite
Anhydrite
Gypsum
Alunogen (solfaterite)
Lanarkite
Alunite
Botryogen (idrizite)
Hanksite
Crocoite

Phosphates

Anapaite (messelite)
Parahopeite
Amblygonite
Apatite (phosphorite, fluorapatite, dahllite)
Rhodophosphite
Manganapatite
Pyromorphite
Mimetite
Vanadinite
Hedyphane
Wavellite
Fischerite

Tungstates

Scheelite
Stolzite (scheelitine)
Wulfenite
Cuprotungstite (cuproscheelite)

MINERALS WITH SILICA

Silica

Quartz
Agate
Chalcedony
Jasper
Tridymite
Cristobalite
Melanophlogite

Silica—Continued

Opal (cacholong, hydrophane)
Hyalite
Silicified wood
Geyserite
Tabasheer
Nesosilicates
Willemite

Infrared-luminescent minerals—Continued

MINERALS WITH SILICA—Continued

Nesosilicates—Continued

Calcium larsenite

Norbergite

Leucophoenicite

Andalusite

Chiastolite

Kyanite (raetizite)

Topaz

Garnets

Grossularite

Andradite

Demantoid

Zoisite (thulite, saussurite)

Epidote

Tawmawite

Zircon

Cyrtolite

Alvite

Sphene

Axinite

Howlite

Tourmaline

Sorosilicates

Hemimorphite

Vanuxemite

Clinohedrite

Wollastonite

Pectolite

Beryl (emerald, aquamarine)

Pseudosmaragd

Idocrase

Californite

Inosilicates

Sillimanite

Fibrolite

Spodumene

Kunzite

Hiddenite

Pyroxenes

Diopside

Jadeite

Diallage

Enstatite

Bronzite

Amphiboles

Tremolite (hexagonite, calamite,
chromtremolite)

Byssolite

Inosilicates—Continued

Amphiboles—Continued

Actinolite

Arfvedsonite

Szechenyiite

Anthophyllite

Serpentine (metaxoite)

Chrysotile

Saponite

Cerolite

Deweylite (gymnite)

Jurupaite

Crestmoreite

Sepiolite

Quincite

Iddingsite

Phyllosilicates

Euclase

Leucophane

Apophyllite

Talc (steatite)

Lucianite

Micas

Muscovite (agalmatolite)

Fuchsite

Lepidolite

Taeniolite

Chlorites

Xanthophyllite

Cookeite

Colerainite

Kaolinite

Confolensite

Montmorillonite

Steargillite

Stevensite

Allophane

Razoumovskyn

Collyrite

Malthacite

Halloysite

Gyrolite

Okenite

Tektosilicates

Nepheline

Trimerite

Infrared-luminescent minerals—Continued

MINERALS WITH SILICA—Continued

Tektosilicates—Continued

Petalite

Analcime

Pollucite

Feldspars

Orthoclase (leelite, lennilite,
delawarite)

Adularia

Microcline (amazonstone)

Hyalophane

Albite

Oligoclase

Andesine

Anorthite

Danburite

Sodalite (molybdosodalite)

Hackmanite

Hauynite

Teklosilicates—Continued

Feldspars—Continued

Scapolite

Meionite (ersbyite)

Stroganovite

Datolite

Zeolites

Natrolite

Hydronephelite

Laubanite

Mesolite

Thomsonite

Harringtonite

Laumontite

Heulandite

Castorite

(hydrocastorite)

Chabazite

Phacolite

All observations of the intensity of infrared luminescence were originally recorded on a numerical scale of 0 to 5 including plus and minus signs and were based entirely on the observer's visual judgment. These original numerical values have all been converted to verbal scales for presentation in this report.

Many specimens in the National Museum are labeled with names now regarded as synonyms for, or subvarieties of, an accepted specie name. These minerals are placed in the tables according to the accepted species name, and cross references are given under the names shown on the specimen label. For some minerals infrared luminescence was found in both the subvariety and the main variety; for others only the subvariety produced luminescence. When the data in the tables apply only to those specimens labeled with the name of a subvariety, this name is indented and placed on a separate line. When, however, the data apply to both the main mineral and its synonyms and subvarieties, these latter names are placed in parenthesis and on the same line as that of the main mineral.

OCCURRENCE OF INFRARED-LUMINESCENT MINERALS

Because the chemical environment of a mineral specimen has a considerable influence on its composition and hence on its luminescence, the locality where the specimen was found is very important.

In many places the activators which cause the luminescence of one species of mineral also cause luminescence in other species found nearby. Table 2 lists the main regions where specimens showing infrared luminescence were found. For each mineral the localities are arranged in three groups—weak, medium, or strong—according to the intensity of infrared luminescence of the minerals found there. Table 3 gives the number of regions represented in the collection and the percentage of these that yielded infrared luminescent specimens.

To keep the locality list moderately short while maintaining a certain amount of precision, areas containing a number of places yielding infrared luminescent specimens are represented either by a regional name (as a county) that does not cover too wide an area, or by the name of a centrally located town supplying most of the minerals showing typical infrared luminescence. Thus, the report of infrared luminescence from one locality may indicate similar occurrences nearby. Indeed, localities are generally regarded as broad areas having a number of mines and sometimes including several counties. For example, each of the following are regarded as one locality: the saline-lake area of Inyo, Kern, and San Bernardino Counties in California; the northern New Jersey mineral district in Sussex and Passaic Counties, N. J., and Orange County, N. Y.; Cumberland, Durham, Westmoreland, Northumberland, and parts of York and Lancaster Counties in England; and the Ural Mountains of Russia.

In the National Museum collection many places are identified by names that could not be found in an atlas, and many others have only general labels. These specimens are usually regarded as the same as another better labeled one from the same area. Thus, if one specimen was labeled merely India, another Chandri-bahara, India (guaranteed not to be in any atlas), and a third Western Ghats, Bombay, India, the first two are deprived of their possible individuality, and all three are lumped as a single locality, labeled as Bombay, India. A fourth specimen labeled Calcutta would, however, be considered another locality. Accordingly the number of localities given in table 3 may be somewhat smaller than the actual number of localities covered by the survey, but the deviation is probably small. Unfortunately, the identity of the localities is only as good as the labels on the specimens, and many of the specimens were presented to the National Museum a long time ago by people who had only a vague idea where they found the mineral. This explains why many localities are identified by only such vague and inclusive names as Africa, India, and Canada. Also many specimens were found when different geographic names

were in use. Japan was once divided into provinces instead of prefectures; Germany and the Balkan States were subdivided into provinces that are no longer compatible with present political boundaries. No attempt has been made to convert the locality names to their modern equivalents. Also, although I have tried to follow modern systems of spelling geographic names, many of the places could not be verified and are presented as they are recorded in the museum catalog. People working with only a few minerals or localities will probably be familiar enough with the areas mentioned to recognize even obsolete spellings.

The lack of a positive report of infrared luminescence in a region does not mean that such specimens cannot be found there. Even if the area is represented by specimens in the National Museum collection, these specimens may have been chosen for some special characteristic such as crystallization, whereas almost all other specimens found in the area have different characteristics and are infrared luminescent. An excellent example is given by the three drawers of calcite specimens from northern New Jersey, many of them from Franklin, which is famous for the brilliant red fluorescence of the calcite found there. However, none of the specimens in those three drawers showed this red fluorescence; these specimens had been chosen for their crystal perfection, and the Franklin calcite crystals were not formed from solutions containing the proper amounts of manganese and lead to show strong fluorescence. However, most of the Franklin willemite and zincite specimens in the National Museum are in a massive calcite gangue that shows extremely brilliant red fluorescence.

Although Franklin, N. J., has long been famous for its large number of fluorescent minerals and for the brilliance of their emission, the infrared luminescence of these minerals is either nonexistent or weak. Indeed no mineral region has been found which produces many varieties of minerals showing intense infrared luminescence. However, weak or medium infrared luminescence is shown by a number of mineral varieties found in some localities. Many of the Franklin, N. J., minerals show such a weak infrared luminescence. Many minerals found near Pikes Peak, Colo., show a weak, but frequently long-wavelength, infrared emission that is believed to result from rare-earth activators. The saline-lake areas of southern California produce many borate and halide minerals that show a weak infrared luminescence, and Melhase (1935) in reporting the accompanying pale-yellow fluorescence of the minerals says that the brine of the lakes also is fluorescent.

ABUNDANCE OF INFRARED LUMINESCENCE

Table 3 is intended to indicate the prevalence of infrared luminescence in minerals. Columns 2 and 3 give the size of the sampling—the number of specimens of the mineral and the number of localities represented. Columns 4, 5, 6, and 7 give the percentages of these specimens and localities that show infrared and visible luminescence. These percentages are given to the nearest 10 percent except that they are given to the nearest unit when less than 10 percent. Percentages are given for both specimens and localities, because either one alone may give biased results for minerals represented by only one or two localities or by a majority of specimens from one locality. Any pieces bearing the same museum number are counted as one specimen, so that the number of samples examined often considerably exceeds the recorded number of specimens. Also, as mentioned above, one locality may cover a broad area and include many mines.

The dependence of most mineral luminescence upon accidental impurities makes statements regarding its occurrence and especially the frequency of the occurrence extremely risky. For example, some 20,000 specimens of about 300 minerals were examined in a preliminary survey; and, although earlier investigators had reported finding fluorescent specimens of every one of these minerals, we did not find a single visible or infrared luminescent specimen for 25 percent of these minerals. Perhaps some of these negative reactions can be explained by a lack of thoroughness in observing visible fluorescence; only a 2,500-Å ultraviolet lamp was used in much of the examination for visible fluorescence. A great many minerals, however, did not show luminescence because the National Museum collection lacks specimens containing the right kind and amount of activators. Even if the right region is represented, suitably activated specimens may be absent; all specimens from one locality seldom show the same luminescence. Only parts of some mineral specimens show luminescence. A few specimens showed a zoned infrared luminescence limited to the base, core, or tips of crystals, and in many sphalerite specimens from Colorado the infrared luminescence is limited to the extreme edges of the crystal surfaces.

FACTORS INFLUENCING THE DETECTION OF WEAK LUMINESCENCE

Perusal of tables 2 and 4 shows that a large proportion of the infrared luminescence was judged by the observer to be weak in intensity. Another large group of minerals showed even weaker

infrared luminescence, but because of the uncertainty of the observation these are not reported.

When the infrared is weak and luminescence occurs in small spots, it is sometimes difficult to be certain, without careful mineralogic examination, whether the mineral being observed is the one that has been identified. Thus, it is possible that much of the infrared luminescence reported for sphalerite is actually caused by greenockite, which always shows infrared luminescence, and which is present in many sphalerite specimens either as a thin surface coating or in solid solution. Similarly much of the weak and spotty infrared luminescence of cryolite and cryolithionite might be caused by small amounts of chiolite which frequently accompanies these minerals, and which much more commonly shows infrared luminescence. Many other minerals show a weak luminescence that seems to result from coating and cavity fillings of impure clay and carbonate alteration products that are commonly slightly luminescent.

Another factor that makes the detection of weak infrared luminescence uncertain is the difficulty of distinguishing it from reflected light "leaked" by the filters (p. 78). Both the viewing box and the scanner contained a weak infrared light source so that the observer could estimate the importance of this infrared reflection; table 4 includes his evaluation of the specimens' reflectivity. The value recorded is that of diffuse reflection; specular reflection for minerals with good cleavage or with metallic luster is much higher. The reflection is recorded as either "very faint," "faint," "average," or "bright." These observations of infrared reflection seldom show any results that cannot be expected from visual examination. Good cleavage surfaces generally show a high degree of specular reflection, and bright matte surfaces a high degree of diffuse reflection. Specimens with a light-brown or reddish color as from a thin ferrous coating are also frequently bright. A few red minerals such as zincite show strong reflection. Dull-black opaque minerals and clear, almost transparent, minerals reflect very little infrared because of complete absorption and complete transmission, respectively.

COMPARISON OF INFRARED AND VISIBLE LUMINESCENCE

Most infrared luminescent minerals have also been reported as visibly fluorescent, but many infrared luminescent specimens do not show visible fluorescence; and, vice versa, many visibly fluorescent specimens do not show infrared luminescence. The preliminary examination of the National Museum mineral collec-

tion was restricted to about 20,000 specimens of 300 minerals for which luminescent phenomena had been reported in at least one of the lists of Engelhardt (1912), Kunz and Baskerville (1903), Krejci-Graf and Krejci-Graf (1934), Walther (1936), Zodac (1936), Deribere (1943, p. 31-46), Dake and DeMent (1941), Warren (1944), DeMent (1945), and in a list of fluorescent minerals in the U. S. National Museum compiled by J. H. Benn (written communication). This preliminary examination disclosed more than 90 percent of all the infrared luminescent specimens found, even though later examinations covered more than 180,000 additional specimens.

There is, thus, an obvious relationship between the two types of luminescence, but the relationship does not imply that the causes of both infrared and visible luminescence are the same. There is ample evidence that some of the activators which cause the strongest and most prevalent visible fluorescence under ultraviolet do not cause any infrared emission. The uranyl-activated silica and uranium minerals, which give a brilliant yellow or green fluorescence under ultraviolet light, show no infrared luminescence. The manganese-activated calcites and willemite from Franklin, N. J., which show spectacular red and yellow-green fluorescence, give little or no infrared emission. Many scheelite and powellite specimens, which always show visible luminescence, do not show infrared emission. However, there are also a number of minerals in which infrared emission is much more common than visible emission. Thus, all specimens of greenockite show a strong infrared emission, but only about half of them give a visible emission with ultraviolet light. Infrared luminescence is also far more common than visible fluorescence in such abundant minerals as feldspars, amphiboles, and pyroxenes. In many other minerals, such as chromium-activated corundum, beryl, jadeite, and kyanite, the infrared luminescence appears much stronger than the visible emission.

We can conclude that, although the activators that cause visible and infrared luminescence are often, if not usually different, the suitability of the host mineral for one activator also often applies to other activators. Thus, scheelite, which owes most of its visible luminescence to the tungstate ion, also can contain rare-earth activators that cause strong infrared luminescence. The suitability of a host mineral for luminescence activators probably involves both the ability of the crystal lattice to hold foreign ions and the transparency of the mineral to both exciting and emitted radiation.

IMPORTANT ACTIVATORS FOR INFRARED LUMINESCENCE

Determination of the cause of luminescence is impossible unless a considerable amount of expensive laboratory equipment is available; precise spectrographic analysis of mineral composition and luminescent emission is essential for the correct identification of activators. Previous investigators have, however, identified the activators responsible for the visible fluorescence of many minerals, and some of these activators are known also to cause infrared luminescence. With such information the cause of the infrared luminescence of some minerals may be assumed, but the assumption is not really justified, because other activators may in some specimens cause at least part of the luminescence. Nevertheless a summary of the activators reported to cause infrared luminescence and of the minerals in which these activators have been found probably provides the best explanation of infrared luminescence that can be made without performing much additional laboratory work. Undoubtedly the list of these activators is not complete, but it includes enough to explain the more brilliant and common infrared emission. The list is primarily based on Kröger's (1948) classification of luminescent minerals according to type of activators.

Cadmium is responsible for the infrared emission of the cadmium sulfide greenockite, apparently the only mineral observed in which luminescence was produced by a major chemical constituent. Gisolf (according to Pringsheim, 1949, p. 607) has shown that the peak of the luminescent emission band of a solid solution of zinc and cadmium sulfides shifts linearly with increasing cadmium content from 4,600 Å in the blue to 7,600 Å in the infrared. Most specimens also show a weak yellow fluorescence, which results from cadmium ions if they are suitably isolated in the lattice (Weyl, 1942, p. 1037, and Inman, Mroz, and Weyl, 1948). Cadmium may also cause some or all of the less common infrared luminescence of the zinc sulfides sphalerite and wurtzite.

The rare earths cause much of the infrared luminescence emitted by minerals. Generally the rare-earth ions are in a trivalent state, so that their outer electron shell is filled, thus forming a shield for the inner unfilled orbits. The electronic transitions corresponding to the lines of the fluorescence spectra take place within these inner orbits where they are protected from the effects of the surrounding atoms. The lines of the luminescence spectra are thus sharp and practically independent of the type of host mineral. The rare-earth emission spectra cover a broad range and extend beyond 8,000 Å, or well into the infrared region; they probably

cause most of the longest wavelength infrared luminescence. Samarium and europium are the most important members of the group but Kröger's (1948) table also mentions infrared luminescence resulting from dysprosium, neodymium, praseodymium, terbium, thulium, and ytterbium.

These rare earths probably cause the infrared luminescence of many of the minerals whose visible fluorescence is found in a great many specimens. For example, Tanaka's spectrographic examination (1924a) of the fluorescence of calcite has shown that manganese is the main activator, although dysprosium, ytterbium, thulium, and samarium may be contributing activators. Most of the infrared emission of calcite can probably be attributed to members of this group of rare-earth elements. The luminescence of fluorite, the mineral in which fluorescence was first recognized, is still the subject of much discussion, but most of its luminescence is now attributed to rare-earth activators. Although rare-earth activators are usually in a trivalent state, the europium, samarium, and ytterbium activators in many fluorites have been reduced by radioactivity to a divalent state with resultant changes in the emission band frequencies (Przibram, 1937). The important luminescence of scheelite and powellite results from the tungstate and molybdate ions (Cannon and Murata, 1944), but Servigne (1938, 1939, and 1940) has shown that in addition to this tungstate luminescence the emission spectra of most scheelites show rare-earth lines which extend into the infrared region. More than three-quarters of the scheelite specimens examined showed this infrared luminescence caused by rare earths, but powellite specimens, for some still unexplained reason, did not show it.

Rare earths also cause the infrared luminescence of other minerals, for which visibly fluorescent specimens are no more common than infrared luminescent specimens. Köhler and Haberlandt (1934, p. 90) have found rare-earth lines in the fluorescence spectrum of apatite, which may show both visible and infrared luminescence, although the two types of emission do not always occur in the same specimen. Haberlandt and Köhler (1939) also attribute the visible fluorescence of feldspars to the divalent europium ion, and the more common infrared luminescence is probably caused by rare earths in either a divalent or trivalent state. For example, amazonstone from Pikes Peak, Colo., commonly shows infrared emission. Tanaka (1924b) has spectrographically identified samarium and ytterbium in the emission spectra of kunzite; but the investigation of infrared luminescence did not find any luminescent specimens of kunzite, perhaps because localities noted for luminescence are not represented in the National Museum

collection. Some borates, especially those from the saline-lake area of California, are infrared luminescent; and the possibility that this luminescence is caused by rare earths is demonstrated by experiments conducted by Nichols and Howes (1926), who found that rare earths produce luminescence in beads of borax flux. Perhaps rare earths may also be the cause of infrared luminescence in minerals commonly associated with other minerals whose luminescence is known to be caused by rare earths. Thus the infrared luminescence of minerals in the cryolite-chiolite group may be caused by rare earths, as many of the infrared luminescent specimens are from Colorado, where they are associated with luminescent fluorite.

By far the most brilliant infrared luminescence results from the chromium ion which gives a series of strong emission bands centered near the border between the visible and infrared. In synthetic ruby, chromium causes a bright red fluorescence; but in kyanite, the emission is almost entirely in the infrared region. This shift in emission wavelength for different minerals can be explained by the fact that the electronic transitions responsible for the fluorescence of chromium take place in the outermost, unfilled shell of the atom and are thus relatively unprotected from the effects of surrounding atoms in the host lattice. Deutschbein (1932) made a thorough study of chromium-activated luminescence and along with Pringsheim (1949) lists the minerals in which such luminescence is found.

The luminescence activator for corundum, the most intensely infrared luminescent mineral found in this investigation, is the chromium ion, which substitutes isomorphously for aluminum in the crystal lattice. Ultraviolet light sometimes excites a red emission, especially in synthetic ruby, which has a very high chromium content, but the infrared emission excited by visible light is far more common. Most of this emission is, however, very close to the visible spectrum. Pale sapphires and light-blue corundum show a weaker infrared luminescence, but emery and dark-blue specimens are sufficiently opaque to quench all luminescence. Some specimens of two other aluminum oxides, spinel and chrysoberyl, show infrared luminescence caused by the chromium ion; and alexandrite, the deep-blue or green chrysoberyl, shows a strong infrared emission.

A number of silicate minerals also show infrared luminescence caused by the chromium ion. Many kyanite specimens show a very strong infrared luminescence, but none show much visible fluorescence under ultraviolet light. Although Pringsheim (1949) reports that its strong doublet emission line has a slightly lower

wavelength than that of ruby, the greater part of its emission seems to have a longer wavelength. Topaz, especially when slightly brownish or sherry colored, shows a strong chromium-activated infrared luminescence that is sometimes accompanied by a very slight and perhaps questionable visible emission under ultraviolet light. Beryl in cloudy or opaque specimens generally gives no luminescence, but relatively clear pieces of most emerald and some aquamarine show a strong infrared luminescence. Except possibly for one specimen of synthetic emerald, the emeralds examined did not show any visible luminescence, but luminescence has been previously detected and definitely attributed to chromium by Deutschbein (1932) and Venkateswaran (1935). Jadeite owes its green color to chromium and also gives a very intense infrared luminescence. However, one difference between jadeite and other chromium-activated minerals should be noted—in jadeite the infrared emission occurs at considerably longer wavelengths. All oriental and some Mexican jades show this infrared luminescence; but nephrite, which is colored by iron, does not show any luminescence. Deutschbein (1932, p. 740) reports that uvarovite is another mineral showing chromium-activated luminescence, but none of the specimens examined produced any infrared luminescence. However, some grossularite and demantoid specimens showed an infrared luminescence that resembles that of the chromium-activated minerals. The infrared luminescence of hiddenite also resembles that of the chromium ion in emerald, and Claffy (1953) has shown that the green color of some hiddenites which do not show visible luminescence is caused by the chromium ion. The green color of other luminescent hiddenites can, however, be caused by the radium irradiation of kunzite specimens (Pringsheim, 1949, p. 659); therefore some of its luminescence has a different cause.

EMISSION

The last column of table 4 indicates the wavelength of the infrared emission, as determined by changing the cutoff filter in front of the snooperscope. "Very short" is used for emission which can be seen only through filter 1 and possibly filter 2, the latter passing less than one-third as much energy as 1. Most of the emission described as very short probably has a wavelength of 7,000 to 7,500 Å. "Short" emission is visible through filters 1 and 2 and usually through filter 3 which passes less than one-quarter of the emission passed by 1. This type of emission probably has a wavelength between 7,500 and 8,000 Å. "Medium" is applied to all emission that is passed by filters 1, 2, and 3 and in

some cases by 4 which cuts the strength to less than one-fifth of that passed by 1. Medium emission probably has a wavelength between 8,000 and 9,300 Å. "Long" emission is passed by all filters, and filter 4 passes more than three-fifths as much energy as filter 1. Most of the emission described as long probably has a wavelength between 9,300 and 9,700 Å. "Very long" is applied to the emission of a few minerals which produce nearly as bright an image through filter 5 as through filter 1. Very long emission has an average wavelength greater than 9,700 Å. (See fig. 26A.)

Any one of these categories can, however, apply to a number of different types of emission spectra. Thus an emission classed as short might consist of a broad band or series of bands extending from 7,000 to 8,300 Å; a single sharp peak at approximately 7,800 Å; or a group of bright bands between 7,000 and 7,500 Å combined with some low intensity bands between 8,500 and 9,000 Å. Furthermore, when the infrared luminescence is weak or very weak it is often difficult for the observer to detect any differences when varying the excitation and emission filters. Indeed, for a few minerals the spectral characteristics of very weak emission have to be recorded as "indeterminable." In general, however, weak luminescence would tend to be recorded as having too short an emission wavelength.

The table shows that infrared luminescence with a short wavelength is more common than luminescence with a longer wavelength. The greater sensitivity of the infrared image tube to short wavelengths might be an explanation of this conclusion, but this sensitivity difference was considered in describing the emission wavelength. A better explanation is provided by the greater efficiency of luminescence processes in which the excitation and emission wavelengths are close together. In the limiting case of resonance luminescence the absorbed radiation has the same frequency as the emitted light, and the efficiency of the process is a maximum. Thus the most efficient infrared luminescence would occur at short wavelengths near to those of the visible excitation.

The wavelength of the luminescence of minerals varies considerably and is seldom the same for all specimens of one mineral or even for all specimens of one mineral activated by the same element. As mentioned on page 91, the wavelength of the luminescent emission caused by the trivalent rare earths is nearly independent of the type of host lattice, but variations in the relative concentrations of the activator elements can change the emission wavelength. Luminescence resulting from the divalent rare earths and most other activators is, however, considerably affected by the nature of the host lattice.

The brilliant infrared luminescence of chromium-activated minerals provides an excellent example of the importance of the host lattice in influencing emission wavelength. Thus, the luminescence wavelength of ruby is classed as "very short" for most specimens, but the wavelength for the much denser minerals kyanite and jadeite is "medium". Deutschbein (1932) has found that the position of one of the brightest lines of the chromium spectrum (6,927 Å in ruby) varies as much as 250 Å among 8 different minerals, and other lines may show an even greater variation. The electronic transitions responsible for the fluorescence of chromium take place in the outermost, unfilled shell of the ion and are thus relatively unprotected from the effects of surrounding atoms in the host lattice. As the transitions are normally forbidden and can occur only because of the electric fields of the surrounding atoms, the probability of any transition and thus the relative strength of the resulting spectral lines depends on the host crystal. Additional subordinate lines can result in the spectra from the vibrational levels of the host lattice and from intermolecular Stark effects. Furthermore, even if the emission spectrum of an ion is independent of the effect of the host lattice, changes in emission spectra may be caused by self-reversal due to changes in concentration of the activator (Pringsheim, 1949, p. 664).

EXCITATION

Columns 6 and 7 of table 4 give the range and most effective color of exciting radiation for various mineral specimens. The tabulations are based on the observations of relative brightnesses of luminescence produced by excitation through the five filters that could be placed in front of the projector in the viewing box. For the convenience of the reader, the filters are described by the color of the light transmitted. These colors and the approximate wavelengths covered by each are listed in table 1 on page 79. In table 4 the "Range of excitation" column lists all filters whose transmitted light produced a detectable luminescence but the "Maximum of excitation" column gives only those filters that were most effective in producing this luminescence. The recording of more than one filter in the "Maximum of excitation" column means that the same brightness was recorded when the specimen was excited through more than one filter.

All the data suggest that the intensity of the infrared luminescence of most minerals decreases rapidly with a decrease in the wavelength of excitation. However, most of this decrease results from relative weakness of the ultraviolet excitation compared to

the red and green excitation (see discussion on p. 75 and data in column 5 of table 1). Even a weaker emission caused by excitation in the violet end of the spectrum can mean that the mineral is actually more sensitive to violet excitation than to red. Accordingly, if the emission caused by short wavelength excitation was equal to that excited by longer wavelengths, the violet or ultraviolet is recorded in the "Maximum of excitation" column. Also the violet or ultraviolet is placed in parentheses as an additional "Maximum of excitation" for specimens in which the emission excited by these wavelengths was large enough to be more than that excited by longer wavelengths if both emission strengths were multiplied by the reciprocal of their excitation energies. Unfortunately, the luminescence under ultraviolet, violet, and blue-violet excitation was recorded as zero intensity for most minerals that showed only weak or very weak infrared luminescence, and such a value cannot be corrected.

Although the data generally show a preponderance of excitation in the red and green end of the spectrum, violet and ultraviolet light are always the most effective form of excitation for marshite, matlockite, mimetite, and phosgenite, and possibly for some specimens of scapolite, hackmanite, sussexite, and xanthophyllite, as well as some carbonates and chromium-activated minerals. Ultraviolet is probably an effective form of excitation for many other minerals, especially for many of those which showed such weak infrared luminescence that the low-energy, short-wavelength sources employed produced no detectable luminescence. Nevertheless, the availability of high-energy red and green light from incandescent sources makes this region the most practical for excitation of infrared luminescence.

Before any luminescence can be emitted from a crystal an electron has to be raised to an excited state by the absorption of energy. Such absorption can take place only if there is an electron transition corresponding to the impinging energy, although, fortunately, owing to the effects of thermal vibration the correspondence does not have to be exact. In resonance luminescence, energy is absorbed by the same transition that causes the luminescence, and the exciting radiation has the same wavelength as the luminescence; the efficiency of the process, therefore, is very high. The luminescence described in this report, however, results from excitation of considerably shorter wavelengths. Accordingly, higher energy levels, either in the same ion or in another part of the crystal, lattice are involved, and the energy is transferred with consequent loss to the level from which the emission takes place. Such a transfer of energy may occur in a number of ways,

and the probabilities of the transitions may depend on many factors involving not only the activators, but all other components of the luminescent system. In many minerals additional activators are required; thus the ultraviolet excitation of calcite fluorescence generally requires the presence of a sensitizing impurity such as lead (Pringsheim, 1949, p. 647; Schulman, Evans, Ginther, and Murata, 1947). In other minerals, however, the absorption can take place directly in the activating atom. Thus, greenockite specimens from Llallagua and most other localities show a maximum excitation efficiency in the green near 5,000 Å, which is, according to Gisolf (*in* Pringsheim, 1949, p. 607), near the fundamental absorption band of cadmium sulfide. The efficiency of excitation of any wavelength will depend, first, on the number of suitable absorption levels, and second, on the probability of energy transfer from these levels to the emission level.

Consideration of the quantum theory of luminescence leads to an additional reason for the decrease of infrared luminescence efficiency at short excitation wavelengths. The luminescence emitted is proportional to the number of excited luminescent centers, and one quantum of light is required to excite each center. The energy of a quantum is proportional to the frequency of the light or inversely proportional to its wavelength. Thus the number of luminescent centers that can be activated by light from each lamp is proportional to the energy times the mean wavelength, which represents the quanta or energy flux per unit area per unit of time. These values are given in column 6 of table 1, and they show an even more rapid decrease with decreasing wavelength than does the energy emitted by the light sources.

An interesting interpretation of the excitation mechanism may partly explain the lack of visible emission from some of the brilliant infrared luminescent chromium-activated minerals. The introduction of chromium adds a broad absorption band in the green at about 5,600 Å (Pringsheim, 1949, p. 644). Excitation close to this band (filters 2, 3, and 4) produces a strong infrared luminescence in all chromium-activated minerals, but ultraviolet excitation causes infrared luminescence in only ruby and a few other minerals. The ultraviolet excitation of ruby also produces a strong red luminescence, and Kröger (1948, p. 84) has shown that the absorption of pure aluminum oxide is very small throughout the visible spectrum but increases rapidly for wavelengths below 3,000 Å. It would thus appear that irradiation with green light results in direct excitation of the chromium ion and is effective for all chromium-activated minerals. Ultraviolet excitation, however, involves the absorption of light by the host lattice and subsequent

transfer to the chromium ion; ultraviolet excitation will thus be effective in only the few chromium-activated minerals that can absorb and then transfer this energy efficiently. As the luminescence of chromium minerals seems to involve the emission of both visible and infrared light, the advantage of the snooperscope for detecting chromium luminescence may result not from its ability to detect infrared radiation, but rather from its use of visible excitation.

POSSIBILITIES FOR PRACTICAL USE

One of the reasons for undertaking this program of investigations was the possibility that the infrared luminescence of minerals might prove a useful prospecting tool. If it is to serve such a purpose a mineral has to be found that will meet the following requisites: The mineral must be of economic importance—either an ore or an associate of ore. It must always show luminescence, which probably means that one of its chemical constituents will be an activator. Thus under ultraviolet light scheelite shows a blue luminescence caused by the tungstate ion, and some uranium minerals show a green luminescence caused by the uranyl ion. In some instances a mineral that always shows infrared luminescence in one locality might be worth considering. Thus ultraviolet light is very useful for detecting manganese-activated zinc minerals at Franklin, N. J. The mineral must be difficult to identify by simpler methods; no one would consider prowling around in the dark with a snooperscope looking for a copper carbonate. The infrared luminescence should be easily distinguished from that produced by less valuable materials. Considering the frequency of weak reactions from clay minerals and the lack of methods for distinguishing wavelength, this might be a serious limitation.

The only mineral that is always luminescent in the infrared region, and thus able to satisfy the second requirement, is greenockite, which is also the only important cadmium mineral. Greenockite occurs as a very thin coating on sphalerite and similar minerals, and is usually extracted as a byproduct of zinc mining.

The brighter infrared luminescence of many chromium-activated gems might be useful. For example, infrared luminescence provides a simple tool for distinguishing most pyroxene jades from their amphibole relatives.

The greatest opportunities for the infrared detection of minerals may result from the possibility of detecting small quantities of rare earths in relatively common minerals like feldspars. As the wavelength of rare-earth luminescence lies in the relatively long infrared, filters could perhaps be used to eliminate the effects of

other activators. The usefulness would depend on the intensity of the infrared luminescence from the common gangue minerals as a guide to concentrations of the rare-earth ore minerals monazite, xenotime, and bastnaesite, which are too opaque to be luminescent. Tests of this relationship would have to be made in individual field localities.

TABLE 2.—*Sources of minerals showing infrared luminescence*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Actinolite-----	Franklin, N. J.-----	-----	Siberia.
Adularia-----	Grisons, Switzerland-----	-----	
Agalmatolite. (See pyrophyllite.)	-----	-----	
Agate. (See quartz.)	-----	-----	
Albite (peristerite.)	Narsarsuk, Greenland-----	-----	
Alexandrite. (See chrysoberyl.)	-----	-----	
Allophane-----	-----	Resin Hollow, Ky-----	
Collyrite-----	Schemnitz, Hungary-----	-----	
Malthacite-----	Steindorfel, Bohemia-----	-----	
Razoumovskyn.	Kossmutz, Siberia-----	-----	
Alunite-----	Allumiere, France-----	Oruro, Bolivia-----	
	Wurzen, Saxony-----	-----	
Alunogen:	-----	-----	
Solfaterite-----	Solfaterra, Italy-----	-----	
Amazonstone. (See microcline.)	-----	-----	
Amblygonite-----	Pala, Calif-----	Harding, N. Mex-----	
Amphibole. (See actinolite, anthophyllite, arfvedsonite, tremolite.)	-----	-----	
Anapaite:	-----	-----	
Messelite-----	Wessel, Germany-----	-----	
Analcime-----	Golden, Colo-----	-----	
Andalusite-----	Fresno City, Calif-----	Lisens Alp, Tyrol-----	
	Swarthmore, Pa-----	-----	
Chastolite-----	Lancaster, Mass-----	-----	
	Cumberland, England-----	-----	
	Baregas, France-----	-----	
Andesine-----	Esterel Mountains, France-----	-----	
Sacchurite-----	-----	Glasendorf, Silesia-----	
Andradite:	-----	-----	
Demantoid-----	-----	-----	
Anglesite-----	Monte Poni, Sardinia-----	Cramford, England-----	
Anhydrite-----	Celle, Hanover, Germany-----	-----	
	Stassfurt, Germany-----	-----	
Anorthite-----	-----	Pala, Calif-----	
Anthophyllite-----	Pylesville, Md-----	-----	
	Minneapolis, N. C-----	-----	

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Apatite.....	Renfrew County, Ontario. Bovey Tracey, England. Blagodot, India..... Toghigi Prefecture, Japan. Greenwood, Maine..... St. Lawrence County, N. Y. Odegaard, Norway... Kola Peninsula, Russia. Gelivara, Sweden..... Grisons, Switzerland.. Twin Peaks, Utah..... Dundarragon, West- ern Australia.	Llallagua, Bolivia.. Haddam, Conn..... Furuholmen, Norway. Amelia, Va.....	Mesa Grande, Calif. Durango, Mexico.
Fluorapatite ..			
Dahllite.....	Manhattan, Nev.....		
Rhodo- phoshite.	Horrsoberg, Sweden.....		
Manganapa- tite.	Westana, Sweden.....		
Apophyllite.....	New Almaden, Calif.. French Creek, Pa.....		
Aquamarine. (See beryl.)			
Aragonite.....	Bahama Islands..... Collingwood, Australia. Girgenti, Sicily..... Mount Vesuvius, Italy Shinano Province, Japan. Eureka district, Nev.. Badlands, Wyo..... Organ Mountains, N. Mex. Couliege, France..... Grape Vine Moun- tains, Nev. Leadville, Colo.....	Bisbee, Ariz..... Sonoma County, Calif. Andover, N. J..... Tintic, Utah.....	
Arfvedsonite: Szechenyiite ..			Burma.
Augite: Omphacite.....		Fichtelgebirge, Germany.	
Axinite.....	Franklin, N. J.....		
Barite.....	Pribram, Bohemia.. Ashe County, N. C.. Black Hills, S. Dak.. Canyon County, Colo.. Smoky Hill, Kans.. Langban, Sweden.....		
Baudisserite. (See magnesite.)			
Bauxite.....	Floyd County, Ga ..		
Bentonite. (See montmorillon- ite.)			

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Calcite—Con-----	Trinity, Calif----- Warren, Ariz----- Suisun City, Calif----- Bleiberg, Carinthia----- Franklin, N. J-----	----- ----- ----- ----- -----	
Calcium larsenite.			
Californite. (See idocrase.)			
Cassinite. (See hyalophane.)			
Castorite. (See petalite.)			
Celestite-----	Warrior, Ala----- Borate, Calif----- Girgenti, Sicily----- Strontian Island, Lake Erie-----	----- ----- ----- -----	
Cerolite. (See saponite.)			
Cerussite-----	Tsumeb, South-west----- Africa----- Matlock, Derbyshire, England----- Joplin, Mo----- Davidson's mine, N. C-----	----- ----- ----- ----- -----	
Cervantite-----	Silver Hill, Sevier County, Ark----- Gulzora, New South Wales-----	Humbolt County, Nev----- Zamora, Spain----- Camp Floyd, Utah-----	Charcas, San Luis Potosi, Mexico----- Toliman, Queretaro Mexico-----
Chalcedony. (See quartz.)			
Chiasolite. (See andalusite.)			
Chiolite-----	Miask, Ural Moun- tains, Russia-----	Ivigut, Greenland-----	
Chlorite. (See cookeite, coler- ainite.)			
Chromtremolite. (See tremolite.)			
Chrysoberyl-----	Ceylon-----	-----	
Alexandrite-----	-----	-----	Katherinenburg, Ural Mountains, Russia-----
Chrysotile. (See serpentine.)			
Colemanite (neo- colemanite).	Lang, Calif-----	-----	
Colerainite-----	Nottingham, Pa-----	-----	
Collyrite. (See al- lophane.			
Confolensite. (See kaolinite.)			
Cookeite-----	Buckfield, Maine----- Pala, Calif-----	----- -----	
Corundum (ruby sapphire).	Ceylon (sapphire)----- Bengal, India----- Hyderabad, India-----	Zoutspanberg, Transvaal----- Seluang, Malay----- Niagara Falls, N. Y-----	Ceylon (ruby).----- Amity, N. Y. Macon County, N. C-----

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Corundum (ruby, sapphire) Con-	Bozeman, Mont.-----	White Mountains, Calif.	Powder Springs, Ga.
	Laurel Creek, Ga.-----	Ural Mountains, Siberia.	Rabun County, Ga.
	Shimerville, Pa.-----	-----	Mysore, India.
Creedite.-----	Wagon Wheel Gap, Colo.	-----	Piedmont, Italy.
Crestmoreite.-----	Crestmore, Calif.	-----	Lander, Wyo.
Cristobalite.-----	-----	Saplores, Durango, Mexico.	Franklin, N. J.
Cryolite.-----	Ivigut, Greenland.-----	Girgenti, Sicily.	-----
Cryolithionite.-----	do.-----	Pikes Peak, Colo.	-----
Cuprite.-----	Wheal Phoenix, Cornwall, England.	Miask, Ural Mountains.	-----
Cuprocalcite. (See calcite.)	-----	-----	-----
Cuproscheelite. (See cuprotungstite.)	-----	-----	-----
Cuprotungstite (cuproscheelite).	Huepac, Mexico.-----	Tonechi, Mexico.	-----
Danburite.-----	La Paz, Lower California.	Fuerte, Mexico.-----	-----
Datolite.-----	Danbury, Conn.-----	-----	-----
Delawarite. (See orthoclase.)	-----	Tadjik, Russia.-----	-----
Demantoid. (See andradite.)	-----	-----	-----
Deweylite (gymnite).	-----	Newcastle County, Del.	-----
Diallage.-----	Orange County, N. Y.	Baltimore, Md.-----	-----
Diamond.-----	South Africa.-----	Texas, Pa.-----	-----
Diaspore.-----	Gumuchdagh, Asia Minor.	Gulsen, Styria.-----	-----
Diopside (lavrovite, melacolite).	Laurel Creek, Ga.-----	Fleims, Tyrol.-----	-----
Dolomite (gurhofite).	Gillis Range, Nev.	Franklin, N. J.-----	-----
-----	Horsjoberg, Sweden.	Brazil.-----	-----
-----	St. Lawrence County, N. Y.	Schemnitz, Czechoslovakia.	-----
-----	Sing Sing, N. Y.-----	-----	-----
-----	Cold Spring, N. Y.-----	Franklin, N. J.	Baikal Lake, Siberia.
-----	St. Louis, Mo.-----	Searcy County, Ark.	-----
-----	Traversella, Italy.-----	-----	-----
Tautoklin.-----	-----	Freiberg, Saxony.-----	-----
Emerald. (See beryl.)	-----	-----	-----
Enstatite.-----	Talcville, N. Y.-----	-----	-----
Epidote.-----	-----	-----	-----
Tawmawite.-----	-----	Myitkyina, Burma	-----

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Ersbyite. (See meionite.)			Villa Rica, Brazil.
Euclase-----			
Feldspars. (See adularia, albite, andesine, anorthoclase, hyalophane, microcline, oligoclase, orthoclase.)			
Fibrolite. (See sillimanite.)			
Fischerite. (See wavellite.)			
Fluorapatite. (See apatite.)			
Fluorite-----	Monroe, Conn.-----	Ouray County, Colo.	Corocoro, Bolivia.
	Middletown, Conn.---	Alma, Colo.-----	Clay Center, Ohio.
	San Juan County, Colo.	Pikes Peak, Colo.--	
	Salgadinho Mine, Brazil.	Haliburton, Ontario.	
	Sweetwater Mountains, Calif.	The Gulf, New South Wales.	
	Swakopmund, Southwest Africa.	Cornwall, England	
	Cumberland, England	Devon, England---	
	Durham, England---	Keokuk, Iowa-----	
	Auvergne, France----	Ivigut, Greenland	
	Freiburg, Germany----	Westmoreland, N. H.	
	Barnthal, Italy-----	St. Louis, Mo.-----	
	Shawneetown, Ill.-----	Omodani, Japan-----	
	Stoneham, Maine-----	Chatham, N. H.-----	
	Marion County, Ky.---	Franklin, N. J.-----	
	Oita, Japan-----	Nertschinsk, Siberia.	
	Essex County, N. Y.---	Banat, Rumania---	
	Amelia Court House, Va.	Shenandoah, Va.---	
	Switzerland-----	Renfrewshire, Scotland.	
Yttriofluorite-----		Hundholmen, Norway.	
Fuchsite. (See muscovite.)			
Garnet. (See andradite, grossularite.)			
Gaylussite-----	Ragtown Lake, Nev.---		
Gearsutite-----		St. Peter's Dome, Colo.	
		Wagon Wheel Gap, Colo.	
Geyserite. (See opal.)			
Gilgerite. (See halloysite.)			

TABLE 2.—*Sources of minerals showing infrared luminescence*—Continued

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Greenockite-----	Llallagua, Bolivia----- Marion County, Ark----- Topaz, Calif----- Friedensville, Pa----- Pribram, Bohemia-----	Granby, Mo----- Modoc County, Calif----- Franklin, N. J----- -----	Llallagua, Bolivia. Bishoptown, Scotland.
Grossularite-----	Big Bar, Butte County, Calif----- Hull, Quebec----- Thetford, Vt----- Morelos, Mexico-----	North Thompson River, British Columbia----- Buffelsfontein, Transvaal----- -----	South Africa.
Gurhofite. (See dolomite.)	Montmarte, France--- Borate, Calif----- Mammoth Cave, Ky--- Lockport, N. Y----- Ihlfeld, Germany----- New Almaden, Calif---	Galapagos Islands-- ----- ----- ----- -----	
Gymnite. (See deweylite.)			
Gypsum (selenite)-			
Gyrolite-----			
Hackmanite. (See sodalite.)			
Halite-----	Borax Lake, Calif-----	Stazunia, Poland---	Rossie, N. Y.
Halloysite (indianaite, glagerite).	Garland County, Ark----- Baumgarten, Germany----- Bedford, Ind----- Leoben, Styria-----	Pala, Calif----- Bergnersreuth, Bavaria----- ----- -----	
Hambergite-----	Helgaraen, Norway---	-----	
Hanksite-----	Searles Lake, Calif---	-----	
Harringtonite. (See thomsonite.)	-----	-----	
Hauynite-----	Laacher See, Germany	-----	
Hedyphane-----	Franklin, N. J-----	-----	
Hemimorphite: Vanuzenite-----	-----	Stirling Hill, N. J--	
Hexagonite. (See tremolite.)	-----	-----	
Hiddenite. (See spodumene.)	-----	-----	
Hornblende-----	-----	-----	
Pargasite-----	-----	Edenville, N. Y---	
Howlite-----	Lang, Calif-----	Wentworth, Nova Scotia-----	
Hyalophane: Cassinite-----	-----	Media, Pa-----	
Hydrocerussite---	Wanlockhead, Scotland-----	-----	
Hydronephelite. (See natrolite.)	Somerville, N. Y-----	-----	
Hydrophane. (See opal.)		-----	
Hydrotalcite-----		-----	
Iddingsite. (See serpentine.)		-----	
Idrizite. (See botryogen.)			

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Idocrase: Californite-----	-----	North Thompson River, British Columbia.	Lindsay, Calif.
Indianaite. (See halloysite.) Jadeite-----	Tenochutlan, Mexico	-----	Magoung, Burma. Niigata Prefecture, Japan. Yunnan, China. Buena Vista de Cueller, Guerrero, Mexico.
Jasper. (See quartz.) Jurupaite----- Kaolinite:	-----	-----	Crestmore, Calif.
Lithomarge----- Confolensite-----	-----	Banat, Hungary----- Confolens, France-----	-----
Kyanite-----	Schomberg, Moravia----- Hillswick, Scotland-----	Belgian Congo----- Brazil-----	Zillerthal, Tyrol. Litchfield County, Conn. Thomaston, Ga.
-----	Lancaster County, S. C.	Langesund, Norway Cumberland, R. I. Yakul, U. S. S. R.-----	Windham, Maine. Yancey and Mitchel Counties, N. C.
-----	-----	Wermland, Sweden. Galax, Va.----- St. Gotthard, Switzerland. Pfitsch, Tyrol-----	Roraas, Norway. Delaware County, Pa. Troitzu, Siberia. Guadalajara, Spain. Charlotte Court House, Va.
Lanarkite----- Laubanite. (See natrolite.) Laumontite:	Leadhills, Scotland-----	-----	-----
Leonhardite----- Retzite-----	Zillerthal, Tyrol-----	Vivero, Lugo, Spain.	-----
Lavrovite. (See diopside.) Lazulite-----	-----	Horrsjoberg, Sweden.	-----
Leadhillite----- Leelite. (See orthoclase.) Lennilite. (See orthoclase.) Leonhardite. (See laumontite.) Lepidolite----- Leucophanite----- Leucophoenicite----- Lithomarge. (See kaolinite.) Lucianite. (See talc.)	Leadhills, Scotland----- ----- ----- ----- ----- Franklin, N. J.-----	----- ----- ----- Grotto Ducci, Elba Laven, Norway-----	-----

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Magnesite (baudisserite).	Hoboken, N. J.-----	Delight, Md.-----	
	Baumgarten, Germany.	Rising Sun, Md.---	
	Baudissero, Italy-----	-----	
Malthacite. (See allophane.)			
Manganapatite. (See apatite.)			
Manganocalcite. (See calcite.)			
Marshite.-----	Chuquicamata, Chile.	-----	
	Broken Hill, New South Wales.	-----	
Matlockite.-----	-----	Cromford, Derby, England.	
Meionite:			
Ersbyite.-----	Pargas, Finland.-----	-----	
Stroganovite.	Baikal Lake, Siberia.---	-----	
Melacolite. (See diopside.)			
Melanophlogite. (See cristobalite.)			
Mellite.-----	Antern, Germany.----	Tula, Russia.-----	
Mesolite.-----	Golden, Colo.-----	-----	
	Antrim, Ireland.-----	-----	
Messelite. (See anapaite.)			
Metaxoite. (See serpentine.)			
Micas. (See muscovite, lepidolite, taeniolite.)			
Microcline (amazonstone).	Pikes Peak, Colo.-----	Fianarantsoa, Madagascar.	
	Urals, Russia.-----	-----	
Mimetite.-----	Tsumeb, South-west Africa.	-----	
Molybdosodalite. (See sodalite.)			
Montmorillonite (steargilite, bentonite).	West Side, Oreg.-----	Montmorillon, France.	
	Glen Riddle, Pa.-----	Paris, Maine.-----	
		Yamagata Prefecture, Japan.	
Stevensite.-----	-----	Paterson, N. J.-----	
Montroydite.		Terlingua, Tex.-----	
Moonstone. (See orthoclase.)			
Mooreite.-----	-----	Stirling Hill, N. J.---	
Muscovite:			
Fuchsite.-----	-----	-----	Brevard, N. C.
Natrolite:			
Laudanite.-----	-----	Steinbruch, Silesia	
Hydronephelite.	Brevig, Norway.-----	-----	
Neocolemanite. (See colemanite.)			

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Nepheline-----	Val di Noto, Sicily-----	-----	-----
"Nitrate salts"-----	Kirovsk, Russia-----	-----	-----
Okenite-----	Clark's Cove, Va-----	-----	-----
-----	Riverside, Calif-----	-----	-----
-----	Godhaven, Greenland-----	-----	-----
Oligoclase-----	Newcastle County, Del-----	-----	-----
-----	St. Lawrence County, N. Y.-----	-----	-----
-----	Delaware County, Pa-----	-----	-----
-----	Mitchell County, N. C.-----	-----	-----
-----	Macon County, N. C.-----	-----	-----
Omphacite. (See augite.)	-----	-----	-----
Oolite. (See calcite.)	-----	-----	-----
Opal (cacholong, hydrophane).	Erandique, Honduras-----	Queretaro, Mexico-----	-----
-----	Dubnik, Czechoslovakia-----	-----	-----
-----	Virgin Valley, Nev-----	-----	-----
-----	Steinham, Belgium-----	-----	-----
-----	Bohemia, Germany-----	-----	-----
-----	Faroe Islands-----	-----	-----
-----	Silesia, Germany-----	-----	-----
-----	Willow Creek, Idaho-----	-----	-----
-----	Veresvagas, Hungary-----	-----	-----
-----	Divide, Colo-----	-----	-----
-----	Madison River, Mont-----	-----	-----
-----	Ruditz, Moravia-----	-----	-----
-----	California-----	-----	-----
Geyselite-----	-----	Yellowstone, Wyo-----	-----
Silicified wood.	Jackson's Hole, Mont-----	-----	Granger, Wyo.
Tabasheer-----	-----	-----	Calcutta, India.
Orthoclase (moonstone).	Globe, Ariz-----	Newcastle County, Del-----	-----
-----	Penticton, British Columbia-----	-----	-----
-----	Mourne Mountains, Ireland-----	Akazu, Owari, Japan-----	-----
-----	Mino Province, Japan-----	Meisan, Korea-----	-----
-----	Fianarantsoa, Madagascar-----	Uto, Sweden-----	-----
-----	Auburn, Maine-----	-----	-----
-----	Goodsprings, Nev-----	-----	-----
-----	Little Rock Creek, Mitchell County, N. C.-----	-----	-----
-----	Ceylon-----	-----	-----
Leelite-----	-----	Chester County, Pa-----	-----
-----	-----	Lenni, Pa-----	-----
Lennilite-----	-----	do-----	-----
Delawarite-----	-----	do-----	-----
Parahopeite-----	Salmo, British Columbia-----	-----	-----
Pargasite. (See hornblende.)	-----	-----	-----
Pectolite-----	Great Notch, N. J-----	-----	-----
-----	Middletown, Calif-----	-----	-----

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Pectolite—Con...	Thetford, Quebec...	-----	-----
Peristerite. (See albite.)	Landalfot, Scotland...	-----	-----
Petalite.....	Londonderry, Western Australia.	-----	-----
	Greenwood, Maine.....	-----	-----
	South-west Africa.....	-----	-----
	Uto, Sweden.....	-----	-----
Castorite.....	Elba Island.....	-----	-----
Phosgenite.....	Derbyshire, England.....	-----	-----
	Monte Ponì, Sardinia.....	-----	-----
Phosphorite. (See apatite.)	-----	-----	-----
Pirssonite.....	Searles Lake, Calif.....	-----	-----
Pisolate. (See calcite.)	-----	-----	-----
Plumbocalcite. (See calcite.)	-----	-----	-----
Pollucite.....	-----	Custer, S. Dak.....	-----
Probertite.....	Ryan, Calif.....	-----	-----
Pseudosmaragd. (See beryl.)	-----	-----	-----
Pyromorphite.....	Mies, Bohemia.....	Cumberland, England.	-----
	Cornwall, England.....	-----	-----
	Phoenixville, Pa.....	-----	-----
	Wolfsberg, Germany.....	-----	-----
Pyrophyllite:	-----	-----	-----
Agalmatolite.....	China.....	-----	-----
Pyroxene. (See also diallage, diopside, enstatite, jadeite, spodumene.)	Franklin, N. J.....	-----	-----
Quartz:	-----	-----	-----
Chalcedony...	Pascadero Beach, Calif.....	Cripple Creek, Colo.	-----
	Death Valley, Calif.....	Tampa Bay, Fla.....	-----
	Auvergne, France.....	-----	-----
	Loch Neagh, Ireland.....	-----	-----
	Iceland.....	-----	-----
	Oniski, Japan.....	-----	-----
	Sonora, Mexico.....	-----	-----
	Guanajuato, Mexico.....	-----	-----
	Black Hills, S. Dak.....	-----	-----
	Laredo, Tex.....	-----	-----
	Antigua, West Indies.....	-----	-----
	Opal, Wyo.....	-----	-----
Agate.....	Brazil.....	San Luis Potosi, Mexico.	-----
	Chagres River, Canal Zone.	-----	-----
	Laramie County, Wyo.....	-----	-----
	Bohemia.....	-----	-----
Jasper.....	San Francisco, Calif.....	Bridger Basin, Wyo.	-----
	Colorado.....	-----	-----
Quincite. (See sepiolite.)	-----	-----	-----

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Razoumovskyn. (See allophane.)			
Reichite. (See calcite.)			
Retzite. (See laumontite.)			
Rhaetizite. (See kyanite.)			
Rhodochrosite-----	Pachuca, Mexico----- Marquette County, Mich.	----- -----	
Rhodophosphite. (See apatite.)			
Ruby. (See corundum.)			
Sacchurite. (See andesine.)			
Saponite:			
Cerolite-----	Texas, Pa----- Frankenstein, Germany.	Dixons quarry, Del. Bluemont, Md----- Kosewitz, Germany.	
Sapphire. (See corundum.)			
Saussurite. (See zoisite.)			
Scapolite-----	Long Hill, Conn----- Bolton, Mass----- Pierrepoint, N. Y----- Ottawa County, Quebec. Texas, Md----- Tsarasaoatra, Madagascar. Arendal, Norway----- Easton, Pa-----	Greenville, Quebec ----- ----- ----- ----- ----- ----- -----	
Scheelite-----	Inyo, Kern, and San Bernardino Counties, Calif.	Yuenna, New South Wales. Bolivia----- Monroe, Conn-----	Hyden, Alaska.
	Santiago, Chile-----	Ryndo, Korea-----	
	Kai, Japan-----	Murray, Idaho-----	
	Carrock Fell, England	Riesengrund, Germany.	
	Hill City, S. Dak----- White Pine County, Nev.	Pitkoranda, Finland.	Otomezaka, Japan.
	Jardine, Mont----- Perak, Malay States--	New Zealand----- Iron Mountain, N. Mex.	Traversella, Italy.
	-----	Minerva, Nev----- Sinaloa, Mexico-----	Sonora, Mexico.
Scheelitine. (See stolzite.)			
Selenite. (See gypsum.)			

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Selensulfur. (See sulfur.)			
Senarmontite		El Antimonio, Sonora, Mexico.	
Sepiolite	North Clay City, Nev.	Bare Hills, Md.	
Quincite	Cher, France		
Serpentine (metaxite). (See also deweylite, saponite.)	Montville, N. J.	Crestmore, Calif.	
Chrysotile	Modum, Norway	Lupipko, Finland	
	Globe, Ariz.	Larchowfu Mountains, Shantung, China.	
	New Haven, Conn.		
	Easton, Pa.		
Iddingsite	Conejos, Colo.	Ryan, Inyo County, Calif.	
Silicified wood (See opal.)			
Sillimanite: Fibrolite		Paris, Maine	Brandywine Springs, Del.
Smithsonite	Marion County, Ark.	Auvergne, France	
	Cumberland, England		
	Laurium, Greece		
	Masua, Sardinia		
	Franklin, N. J.		
Sodalite (molybdosalite): Hackmanite	Vesuvius, Italy		
		Kola Peninsula, Russia.	
		Bancroft, Ontario.	
		Magnet Cove, Ark.	
		Kangerdluarsk, Greenland.	
Solfaterite. (See alunogen.)	Clear Creek County, Colo.	Kremmling, Colo.	Santander, Spain.
Sphalerite	Oruro, Bolivia	Southampton, Mass.	Pulaski, Va.
		Galena, Kans.	Banner district, Idaho.
	Roxbury, Conn.	Butler, Tenn.	
	Perkiomen, Pa.		
	Kapnik, Rumania		
	Tsumeb, South-west Africa.		
	Rodna, Rumania		
	Zlatoust, Siberia		
Sphene	St. Gotthard, Switzerland.		
		Ceylon	Sparta, N. J.
Spinel	Taos County, N. Mex.		
Spodumene			Hiddenite, N. C.
Hiddenite			
Steargilite. (See montmorillonite.)			
Steatite. (See talc.)			

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Stevensite. (See montmorillonite.)			
Stibianite. (See stibiconite.)			
Stibiconite-----	Oruro, Bolivia----- Sarawak, Borneo----- Empire district, Nev-----		
Stibianite-----		Potosi, Bolivia-----	
Stolzite:			
Scheelitine-----	Altenberg, Saxony-----		
Stroganovite. (See meionite.)			
Strontianite-----	Strontian, Scotland-----		
Sulfur:			
Selensulfur-----	Cianciana, Sicily-----		
Sussexite-----	Franklin, N. J.-----		
Szenchenyiite (See arfvedsonite.)			
Tabasheer. (See opal.)			
Taeniolite-----	Magnet Cove, Ark-----		
Talc (steatite)-----	Franklin, N. J.----- St. Lawrence County, N. Y.----- Alma, Colo----- Rockland, Maine----- Sonora, Mexico----- Luca Almenia, Spain-----	Manhattan, Nev-----	
Lucianite-----		Villar de Puerco, Spain.	
Tautoklin. (See dolomite.)			
Tawmawite. (See epidote.)			
Terlinguaite-----	Terlingua, Tex-----		
Thomsonite-----	Golden, Colo-----	Kandern, Bohemia	
Harringtonite-----		Belfast, Ireland-----	
Thulite. (See zoisite.)			
Topaz-----	Grosmont, Western Australia.	New England, New South Wales. Minas Geraes, Brazil.	Minas Geraes, Brazil. Scheckenstein, Germany. Sanarka River, Russia.
Tourmaline-----	King's Bridge, N. Y.-----	Franklin, N. J.----- Etchison, Md.----- Kragero, Norway----- Outokumpo, Finland.	
Tremolite (calamite, hexagonite, chromtremolite).	Canaan, Conn----- St. Marcel, Italy----- Rock Raven, Md----- Lee, Mass----- Fowler, N. Y.-----		Stirling Hill, N. J.
Byssolite-----		Johns Mansville Mines, Quebec.	
Tridymite-----	Durango, Mexico-----		
Trimerite-----	Langban, Sweden-----		

TABLE 2.—*Sources of minerals showing infrared luminescence—Continued*

Mineral	Sources of minerals showing infrared luminescence of strength indicated		
	Weak	Medium	Strong
Ulexite.....	Mount Blanco, Inyo County, Calif.	-----	
Valentinite.....	Constantine, Algiers..	-----	
Valleite. (See anthophyllite.)			
Vanadinite.....	Yuma County, Ariz. . .	-----	
	Tucson, Ariz.....	-----	
	Silver district, Ariz. .	-----	
Vanuxemite. (See hemimorphite.)			
Wavellite.....	Llallagua, Bolivia.....	-----	
	Barnstable, England..	-----	
Fischerite.....	Hungary.....	-----	
Willemite.....	Sussex County, N. J. .	-----	
Wollastonite.....	Cordova, Argentina..	Lugo, Spain.....	
	Chelsea, Ontario.....	-----	
	Natural Bridge, N. Y. .	-----	
	Easton, Pa.....	-----	
Wulfenite.....	Yuma County, Ariz. . .	-----	
	Tiger, Ariz.....	-----	
	Pribram, Bohemia.....	-----	
	Organ Mountains, N. Mex.	-----	
Wurtzite.....	Butte, Mont.....	-----	
Xanthophyllite.....	Slatoust, Siberia.....	-----	
Yttriofluorite. (See fluorite.)			
Zeolites. (See laumontite, mesolite, natrolite, thomsonite.)			
Zoisite (thulite, saussurite).	-----	Mount Rosa, Switzerland.	

TABLE 3.—*Abundance of infrared and visible luminescence in minerals*

Mineral	Number of —		Infrared luminescence		Visible fluorescence	
			Percent of —		Percent of —	
	Specimens	Localities	Specimens	Localities	Specimens	Localities
Actinolite.....	63	31	1	3	0	0
Adularia.....	45	10	2	10	0	0
Agalmatolite. (See pyrophyllite.)						
Agate. (See quartz.)						
Albite (peristerite).....	70	25	3	4	1	4
Alexandrite. (See chrysoberyl.)						
Allophane.....	16	12	6	8	30	30
Malthacite.....	1	1	100	100	100	100
Collyrite.....	8	1	60	100	60	100
Razoumovskyn.....	2	1	100	100	100	100
Alunite.....	25	12	8	20	8	20
Alunogen:						
Solfaterite.....	1	1	100	100	100	100

TABLE 3.—*Abundance of infrared and visible luminescence in minerals—Continued*

Mineral	Number of —		Infrared luminescence		Visible fluorescence	
			Percent of —		Percent of —	
	Specimens	Localities	Specimens	Localities	Specimens	Localities
Amazonstone. (See microcline.)						
Amblygonite.....	23	10	10	10	10	20
Amphibole. (See actinolite, anthophyllite, arfvedsonite, tremolite.)						
Anapaite:						
Messelite.....	4	1	20	100	20	100
Analcime.....	84	19	2	5	2	5
Andalusite.....	31	15	30	20	30	30
Chiastolite.....	18	10	20	30	20	40
Andesine.....	24	11	8	9	8	9
Sacchurite.....	2	1	100	100	100	100
Andradite:						
Demantoid.....	15	5	10	20	0	0
Anglesite.....	60	16	7	20	30	60
Anhydrite.....	44	17	7	10	5	6
Anorthite ¹	19	10	5	10	5	10
Anthophyllite.....	24	13	8	15	0	0
Apatite (phosphorite).....	174	30	50	60	50	50
Fluorapatite.....	1	1	100	100	0	0
Dahllite.....	11	5	10	20	20	40
Rhodophosphite.....	1	1	100	100	100	100
Manganapatite.....	3	1	30	100	30	100
Apophyllite.....	112	23	7	10	20	30
Aquamarine. (See beryl.)						
Aragonite.....	115	36	20	40	40	70
Arfvedsonite:						
Szechenyiite.....	1	1	100	100	100	100
Augite:						
Omphacite.....	3	1	70	100	0	0
Axinite.....	51	12	2	10	10	20
Barite.....	185	45	7	10	10	10
Baudisserite. (See magnesite.)						
Bauxite.....	13	7	7	10	7	10
Bentonite. (See montmorillonite.)						
Beryl (emerald, aquamarine).....	215	32	20	30	3	10
Pseudosmaragd.....	1	1	100	100	0	0
Botryogen:						
Idrizite.....	1	1	100	100	100	100
Brucite.....	28	11	10	7	30	40
Bustamite.....	12	3	30	30	30	30
Byssolite. (See tremolite.)						
Cacholong. (See opal.)						
Calamite. (See tremolite.)						
Calcite (manganocalcite, cuprocalcite, reichite, oolite, pisolite, plumbo-calcite).....	470	73	20	40	30	50
Calcium larsenite.....	7	1	90	100	30	100
Californite. (See idocrase.)						
Cassinite. (See hyalophane.)						
Castorite. (See petalite.)						
Celestite.....	92	23	15	30	30	50

¹ Coating?

TABLE 3.—*Abundance of infrared and visible luminescence in minerals—Continued*

Mineral	Number of —		Infrared luminescence		Visible fluorescence	
			Percent of —		Percent of —	
	Specimens	Localities	Specimens	Localities	Specimens	Localities
Cerolite. (See saponite.)						
Cerussite.....	150	31	4	10	10	30
Cervantite.....	12	9	70	80	0	0
Chalcedony. (See quartz.)						
Chiastolite. (See andalusite.)						
Chiolite.....	7	2	60	100	0	0
Chlorite. (See cookeite, colerainite.)						
Chromtremolite. (See tremolite.)						
Chrysoberyl.....	33	8	3	10	10	10
Alexandrite.....	6	1	100	100	10	100
Chrysotile. (See serpentine.)						
Colemanite (neocolemanite).....	33	2	60	100	100	100
Colerainite.....	3	1	100	100	100	100
Collyrite. (See allophane.)						
Confolensite. (See kaolinite.)						
Cookeite.....	13	3	40	70	0	0
Corundum (ruby, sapphire).....	170	26	60	50	10	20
Creedite.....	8	2	10	50	100	100
Crestmoreite.....	7	1	100	100	100	100
Cristobalite.....	30	14	3	7	30	30
Melanophlogite.....	7	1	10	100	10	100
Cryolite.....	27	3	40	100	0	0
Cryolithionite.....	3	1	100	100	0	0
Cuprite.....	73	26	1	4	0	0
Cuprocalcite. (See calcite.)						
Cuproscheelite. (See cuprotungstite.)						
Cuprotungstite (cuproscheelite).....	14	8	40	50	90	80
Danburite.....	34	10	9	10	20	30
Datolite.....	109	16	1	6	5	20
Delawarite. (See orthoclase.)						
Demantoid. (See andradite.)						
Deweylite (gymnite).....	21	8	80	60	80	60
Diallage.....	14	11	10	10	0	0
Diamond.....	20	6	10	30	0	0
Diaspore.....	33	11	20	50	15	20
Diopside (lavrovite, melacolite).....	55	17	5	20	0	0
Dolomite (gürhofite).....	60	25	5	10	20	30
Tautoklin.....	1	1	100	100	100	100
Emerald. (See beryl.)						
Enstatite.....	23	9	4	10	0	0
Epidote: Tawmawite.....	2	2	50	50	0	0
Ersbyite. (See melonite.)						
Euclase.....	7	4	30	20	30	20

TABLE 3.—*Abundance of infrared and visible luminescence in minerals—Continued*

Mineral	Number of —		Infrared luminescence		Visible fluorescence	
			Percent of —		Percent of —	
	Specimens	Localities	Specimens	Localities	Specimens	Localities
Feldspars. (See adularia, albite, andesine, anorthite, hyalophane, microcline, oligoclase, orthoclase.)						
Fibrolite. (See sillimanite.)						
Fischerite. (See wavellite.)						
Fluorapatite. (See apatite.)						
Fluorite	274	46	40	60	50	60
Yttriofluorite	5	1	100	100	100	100
Fuchsite. (See muscovite.)						
Garnet. (See andradite, grossularite.)						
Gaylussite	10	6	30	10	30	20
Gearskite	9	3	20	30	20	30
Geyserite. (See opal.)						
Glagerite. (See halloysite.)						
Greenockite	30	10	60	80	10	40
Grossularite	43	26	30	20	0	0
Gurhofite. (See dolomite.)						
Gymnite. (See deweylite.)						
Gypsum (selenite)	123	38	15	20	40	50
Gyrolite	4	4	20	20	70	70
Hackmanite. (See sodalite.)						
Halite	57	19	7	10	20	50
Halloysite (indianaite, glagerite)	21	18	30	30	20	30
Hambergite	3	2	30	50	30	50
Hanksite	16	1	6	100	40	100
Harringtonite. (See thomsonite.)						
Hauynite	20	4	5	20	5	20
Hedyphane	10	3	30	30	10	30
Hemimorphite: Vanuxemite	6	1	100	100	100	100
Hexagonite. (See tremolite.)						
Hiddenite. (See spodumene.)						
Hornblende: Pargasite	4	3	70	70	0	0
Howlite	16	2	40	100	30	100
Hyalophane: Cassinite	6	1	20	100	0	0
Hydrocerussite	12	5	20	60	10	20
Hydronephelite. (See natrolite.)						
Hydrophane. (See opal.)						
Hydrotalcite	8	3	20	30	0	0
Iddingsite. (See serpentine.)						
Idocrase: Californite	10	2	50	100	0	0
Idrizite. (See botryogen.)						
Indianaite. (See halloysite.)						

TABLE 3.—*Abundance of infrared and visible luminescence in minerals—Continued*

Mineral	Number of —		Infrared luminescence		Visible fluorescence	
			Percent of —		Percent of —	
	Specimens	Localities	Specimens	Localities	Specimens	Localities
Jadeite.....	18	5	50	100	0	0
Jasper. (See quartz.)						
Jurupaite.....	3	1	100	100	100	100
Kaolinite:						
Lithomarge.....	3	3	30	30	30	30
Confolensite.....	1	1	100	100	100	100
Kyanite (rhaetizite).....	59	25	80	80	3	4
Lanarkite.....	5	1	20	100	40	100
Laubanite. (See natrolite.)						
Laumontite:						
Leonhardite.....	3	2	30	50	30	50
Retzite.....	1	1	100	100	0	0
Lavrovite. (See diopside.)						
Lazulite.....	28	9	3	10	0	0
Leadhillite.....	21	9	5	20	10	20
Leelite. (See orthoclase.)						
Lennilite. (See orthoclase.)						
Leonhardite. (See laumontite.)						
Lepidolite.....	50	17	4	6	0	0
Leucophanite.....	4	1	70	100	70	100
Leucophoenicite.....	9	6	50	10	0	0
Lithomarge. (See kaolinite.)						
Lucianite. (See talc.)						
Magnesite (baudisserite) ..	40	25	20	20	20	20
Malthacite. (See allophane.)						
Manganapatite. (See apatite.)						
Manganocalcite. (See calcite.)						
Marshite.....	5	2	80	100	80	100
Matlockite.....	4	2	70	50	70	50
Meionite:						
Ersbyite.....	2	2	50	50	50	50
Stroganovite.....	2	1	50	100	50	100
Melacolite. (See diopside.)						
Melanophlogite. (See cristobalite.)						
Mellite.....	8	2	30	100	90	100
Mesolite.....	23	9	10	20	10	30
Messelite. (See anapaite.)						
Metaxoite. (See serpentine.)						
Micas. (See lepidolite, muscovite, taeniolite.)						
Microcline (amazonstone) ..	95	22	20	10	0?	0?
Mimetite.....	50	14	2	7	0	0
Molybdosodalite. (See sodalite.)						
Montmorillonite (steargilite, bentonite) ..	19	12	70	60	70	60
Stevensite.....	9	1	90	100	90	100
Montroydite.....	3	1	70	100	0	0
Moonstone. (See orthoclase.)						

TABLE 3.—*Abundance of infrared and visible luminescence in minerals—Continued*

Mineral	Number of —		Infrared luminescence		Visible fluorescence	
			Percent of —		Percent of —	
	Specimens	Localities	Specimens	Localities	Specimens	Localities
Mooreite.....	2	1	50	100	50	100
Muscovite:						
Fuchsite.....	14	10	7	10	0	0
Natrolite:						
Laubanite.....	2	1	50	100	50	100
Hydronephelite.....	5	5	40	40	40	40
Neocolemanite. (See colemanite.)						
Nepheline.....	34	12	6	15	3	8
"Nitrate salts".....	9	4	20	20	20	20
Okenite.....	10	4	30	50	50	50
Oligoclase.....	35	12	20	30	6	20
Omphacite. (See augite.)						
Oolite. (See calcite.)						
Opal (cacholong, hydrophane).....	197	68	15	10	20	30
Geyserite.....	7	2	40	50	20	50
Silicified wood.....	8	5	40	60	60	50
Tabasheer.....	3	1	70	100	70	100
Orthoclase (moonstone).....	132	42	9	20	6	10
Leelite.....	3	2	70	100	70	100
Lennilite.....	4	1	50	100	50	100
Delawarite.....	1	1	100	100	100	100
Parahopeite.....	5	2	50	60	50	60
Pargasite. (See hornblende.)						
Pectolite.....	55	11	15	40	30	50
Peristerite. (See albite.)						
Petalite.....	27	11	3	5	3	5
Castorite.....	2	2	50	50	0	0
Phosgenite.....	22	8	15	20	40	40
Phosphorite. (See apatite.)						
Pirssonite.....	23	1	20	100	0	0
Pisolite. (See calcite.)						
Plumbocalcite. (See calcite.)						
Pollucite.....	18	5	6	20	6	20
Probertite.....	5	1	60	100	0	0
Pseudosmaragd. (See beryl.)						
Pyromorphite.....	94	26	10	20	7	20
Pyrophyllite:						
Agalmatolite.....	5	3	40	30	60	40
Pyroxene.....	48	10	2	10	2	10
(See also diallage, diopside, enstatite, jadeite, spodumene.)						
Quartz:						
Chalcedony.....	112	40	15	30	30	60
Agate.....	95	25	5	20	15	40
Jasper.....	84	42	3	7	7	7
Quincite. (See sepiolite.)						
Razoumovskyn. (See allophane.)						
Reichite. (See calcite.)						
Retzite. (See laumontite.)						
Rhaetizite. (See kyanite.)						
Rhodochrosite.....	73	18	3	10	4	20

TABLE 3.—*Abundance of infrared and visible luminescence in minerals—Continued*

Mineral	Number of —		Infrared luminescence		Visible fluorescence	
			Percent of —		Percent of —	
	Specimens	Localities	Specimens	Localities	Specimens	Localities
Rhodophosphite. (See apatite.)						
Ruby. (See corundum.)						
Sacchurite. (See andesine.)						
Saponite:						
Cerolite.....	7	4	90	100	90	100
Sapphire. (See corundum.)						
Saussurite. (See zoisite.)						
Scapolite.....	75	13	20	70	20	80
Scheelite.....	93	30	60	90	100	100
Scheelinite. (See stolzite.)						
Selenite. (See gypsum.)						
Selensulfur. (See sulfur.)						
Senarmontite.....	6	3	20	30	0	0
Sepiolite.....	18	14	10	15	20	30
Quincite.....	8	1	60	100	60	100
Serpentine (metaxite).....	65	24	5	10	5	10
(See also deweylite, saponite.)						
Chrysotile.....	20	12	20	30	20	20
Iddingsite.....	7	2	30	100	50	100
Silicified wood. (See opal.)						
Sillimanite:						
Fibrolite.....	5	4	60	70	60	70
Smithsonite.....	88	27	9	20	30	40
Sodalite (molybdosodalite).....	39	12	5	8	10	15
Hackmanite.....	5	5	60	60	100	100
Solfaterite. (See alunogen.)						
Sphalerite.....	210	51	9	20	3	8
Sphene.....	105	21	8	10	1	5
Spinel.....	70	14	9	15	6	15
Spodumene.....	30	13	7	8	7	8
Hiddenite.....	12	1	90	100	0	0
Steargillite. (See montmorillonite.)						
Steatite. (See talc.)						
Stevensite. (See montmorillonite.)						
Stibianite. (See stibiconite.)						
Stibiconite.....	3	3	100	100	0	0
Stibianite.....	1	1	100	100	0	0
Stolzite:						
Scheelinite.....	1	1	100	100	0	0
Stroganovite. (See meionite.)						
Strontianite.....	25	10	4	10	60	60
Sulfur (selensulfur).....	86	35	2	3	1	2
Susselite.....	9	4	20	20	0	0
Szechenyiite. (See arfvedsonite.)						
Tabasheer. (See opal.)						
Taeniolite.....	3	2	30	50	30	50
Talc (steatite).....	53	23	20	20	20	20
Lucianite.....	1	1	100	100	100	100
Tautoklin. (See dolomite.)						
Tawmawite. (See epidote.)						

TABLE 3.—*Abundance of infrared and visible luminescence in minerals—Continued*

Mineral	Number of —		Infrared luminescence		Visible fluorescence	
			Percent of —		Percent of —	
	Specimens	Localities	Specimens	Localities	Specimens	Localities
Terlinguaite.....	6	2	15	50	70	50
Thomsonite.....	58	19	5	10	7	15
Harringtonite.....	3	2	30	50	30	50
Thulite. (See zoisite.)						
Topaz.....	165	26	15	15	10	10
Tourmaline.....	280	39	3	5	10	10
Tremolite (calamite, hexa- gonite, chromtremolite).....	68	22	20	40	20	50
Byssolite.....	12	9	8	10	8	10
Tridymite.....	18	9	15	10	15	10
Trimerite.....	7	1	100	100	0	0
Ulexite.....	29	8	3	10	20	30
Valentinite.....	17	9	6	10	6	10
Valleite. (See anthophyllite.)						
Vanadinite.....	78	15	6	15	0	0
Vanuxemite. (See hemimorphite.)						
Wavellite.....	66	12	6	20	40	70
Fischerite.....	3	2	30	50	70	100
Willemite ²	93	12	4	8	90	80
Wollastonite.....	34	12	15	40	60	70
Wulfenite.....	87	23	20	20	0	0
Wurtzite.....	23	8	4	10	0	0
Xanthophyllite.....	10	3	10	30	0	0
Yttriofluorite. (See fluorite.)						
Zeolites. (See laumontite, mesolite, natrolite, thomsonite.)						
Zoisite (thulite): Saussurite.....	31	18	3	6	0	0

² Infrared questioned.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Actinolite	Franklin, N. J.	None	Zero	Faint.
Adularia	St. Gotthard, Switzerland	do.	do.	Bright.
Agmatolite. (See pyrophyllite.)				
Agate. (See quartz.)				
Albite	Narsarsuk, Greenland	do.	do.	Average.
Peristerite	Hybla, Ontario	do.	do.	Do.
Alexandrite. (See chrysoberyl.)				
Allophane	Resin Hollow, Ky.	Green	Medium	Bright.
Malthacite	Steindorferl, Czechoslovakia	Pale gray	Weak	Do.
Collyrite	Schemnitz, Hungary	Pale brown	do.	Average.
Razoumovskyn	Kosmutz, Siberia	Gray	do.	Do.
Alumite	Allumiere, France	do.	do.	Do.
Alunogen:				
Solfaterite	Solfaterra, Italy	None	Zero	Bright.
Amazonstone. (See microcline.)				
Amblygonite	Pala, Calif.	Buff	Weak	Average.
	Harding, N. Mex.	Pale brown	do.	Do.
Ambipohle. (See tremolite, actinolite, arvedsonite, and anthophyllite.)				
Anapaite:				
Messelite	Messel, Germany	Pale blue green	do.	Do.
Analcime	Golden, Colo.	Cream white	do.	Bright.
Andalusite	Lisens Alps, Tyrol	None	Zero	Average.
Chiasolite	Lancaster, Mass.	Brown	Weak	Do.
	Baregas, France	do.	do.	Do.
Andesine	Esterel Mountains, France	Pink	do.	Do.
Saccharite	Glasendorf, Silesia	Ochre	Medium	Do.
Andradite:				
Demantoid	Siberia	None	Zero	Faint.

Mineral	Locality	Infrared luminescence			
		Strength	Range of excitation	Maximum of excitation	Emission wavelength
Actinolite	Franklin, N. J.	Weak	Red, green	Red	Short.
Adularia	St. Gotthard, Switzerland	Medium	Red through violet	do.	Do.
Agmatolite. (See pyrophyllite.)					
Agate. (See quartz.)					
Albite	Narsarsuk, Greenland	Weak	Red	do.	Do.
Peristerite	Hybla, Ontario	Very weak	do.	do.	Medium.
Alexandrite. (See chrysoberyl.)					
Allophane	Resin Hollow, Ky.	Medium	Red through violet	Red, green	Short.
Malthacite	Steindorff, Czechoslovakia	Weak	Red, green	Red	Very short.
Collyrite	Schemnitz, Hungary	do.	Red, green, violet	Red (violet)	Short.
Razoumovskyn	Kosmutz, Siberia	do.	Red, violet	Violet	Do.
Alumite	Allumiere, France	do.	Green, blue	Green, blue	Do.
Alunogen		do.	Red, green, violet	Violet	Medium.
Solfaterite	Solfaterra, Italy				
Amazonstone. (See microcline.)					
Amblygonite	Pala, Calif.	Weak	Red, blue	Red	Very short.
	Harding, N. Mex.	Medium	Red, green, violet	Red (violet)	Medium.
Amphibole. (See tremolite, actinolite, arfvedsonite, and anthophyllite.)					
Anapaite:					
Messelite	Messel, Germany	Weak	Red through violet	Red through blue	Do.
Analcime	Golden, Colo.	Very weak	Red through blue	Red	Do.
Andalusite	Lisens Alps, Tyrol	Medium	do.	do.	Short.
Chastolite	Lancaster, Mass.	Weak	Blue	Blue	Do.
	Baregas, France	do.	Red through blue	Red through blue	Do.
Andesine	Estrel Mountains, France	do.	Red	Red	Medium.
Andradite:	Glasendorf, Silesia	Medium	Red, green	do.	Short.
Demantoid	Siberia	Strong	Red through blue-violet	do.	Do.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Anglesite.....	Crumford, England.....	Yellow.....	Medium.....	Average.
Anhydrite.....	Monte Ponì, Sardinia.....	Green.....	Weak.....	Do.
Anorthite.....	Celle, Germany.....	None.....	Zero.....	Do.
Anthophyllite.....	Pala, Calif.....	Pale brown.....	Weak.....	Bright.
Apatite.....	Pylesville, Md.....	None.....	Zero.....	Do.
	Llallagua, Bolivia.....	Cream white.....	Medium.....	Average.
	Mesa Grande, Calif.....	Ochre.....	Strong.....	Do.
	Renfrew, Ontario.....	None.....	Zero.....	Do.
	Guano Island, West Indies.....	Pale green.....	Weak.....	Do.
	Kola Peninsula, Russia.....	None.....	Zero.....	Do.
	Durango, Mexico.....	Brown.....	Weak.....	Do.
Phosphorite.....	Ciply, Belgium.....	Pale green.....	do.....	Do.
Fluorapatite.....	Dundarragon, Western Australia.....	None.....	Zero.....	Do.
Dahlite.....	Manhattan, Nev.....	Cream white.....	Weak.....	Do.
Rhodophosphite.....	Horsjoberg, Sweden.....	Ochre.....	do.....	Do.
Manganapatite.....	Westana, Sweden.....	do.....	do.....	Do.
Apophyllite.....	New Almaden, Calif.....	Brown.....	do.....	Do.
Aquamarine. (See beryl)				
Aragonite.....	Bisbee, Ariz.....	Cream white.....	do.....	Bright.
	Girgenti, Sicily.....	White.....	do.....	Average.
	Tairamura, Japan.....	Pink.....	do.....	Do.
Arfvedsonite:				
Szechenyiite.....	Burma.....	None.....	Zero.....	Very faint.
Augite:				
Omphacite.....	Fichtelgebirge, Germany.....	do.....	do.....	Do.
Axinite.....	Franklin, N. J.....	Red.....	Medium.....	Average.
Barite.....	Příbram, Czechoslovakia.....	Gray.....	do.....	Do.
	Cheyenne River, S. Dak.....	Yellow.....	do.....	Do.
Baudisserite. (See magnesite.)				
Bauxite.....	Floyd County, Ga.....	Gray.....	Weak.....	Do.

Mineral	Locality	Infrared luminescence			Emission wavelength
		Strength	Range of excitation	Maximum of excitation	
Anglesite	Crumford, England	Medium	Green through violet	Blue, blue-violet	Short.
Anhydrite	Monte Ponti, Sardinia	Weak	Green through blue-violet	Blue	Do.
Anorthite	Celle, Germany	do.	Green, blue	Green, blue	Very short.
Anthophyllite	Pala, Calif	Medium	Red through blue-violet	Red, green	Medium.
Apatite	Pylesville, Md.	Weak	Red, violet	Violet	Very short.
	Llallagua, Bolivia	Medium	Red through violet	Red through blue	Long.
	Mesa Grande, Calif	Strong	do.	Green, blue	Do.
	Renfrew, Ontario	Weak	Red through blue	Red	Medium.
	Guano Island, West Indies	do.	Red through violet	Green	Short.
	Kola Peninsula, Russia	do.	Red, green	Red, green	Very long.
Phosphorite	Durango, Mexico	Strong	Red through blue-violet	do.	Medium.
Fluorapatite	Ciply, Belgium	Weak	Red	Red	Short.
	Dundarragon, Western Australia	Very weak	Indeterminable	Indeterminable	Do.
Dahllite	Manhattan, Nev.	Weak	Red through blue-violet	Red	Do.
Rhodophosphite	Horsjoberg, Sweden	do.	Red through blue	Red through blue	Medium.
Manganapatite	Westana, Sweden	do.	Red through blue-violet	Red, green	Long.
Apophyllite	New Almaden, Calif	do.	Red through blue	Red through blue	Do.
Aquamarine. (See beryl.)					
Aragonite	Bisbee, Ariz.	Medium	do.	do.	Short.
	Girgenti, Sicily	Weak	Red through blue-violet	Red	Very short.
	Taimamura, Japan	do.	Green, blue	Green	Short.
Artvedsonite:	Burma	Strong	Red through blue-violet	Red	Medium.
Szechenyiite					
Augite	Fichtelgebirge, Germany	Medium	Red through blue	do.	Do.
Omphacite	Franklin, N. J.	Weak	Green through blue-violet	Green through blue-violet	Very short.
Axinite	Pribram, Czechoslovakia	do.	do.	do.	Long.
Barite	Cheyenne River, S. Dak.	Very weak	Red through blue	Red through blue	Indeterminable.
Baudisserite. (See magnesite.)					
Bauxite	Floyd County, Ga.	do.	do.	do.	Do.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Bentonite. (See montmorillonite.)				
Beryl.....	Muzo, Colombia	None	Zero	Average.
	Kongsberg, Norway	do.	do.	Do.
	Alexander County, N. C.	do.	do.	Do.
		Red	Very weak	Do.
Synthetic emerald.....				
Pseudosmaragd.....	Fahlun, Sweden	None	Zero	Do.
Botryogen:				
Idrizite.....				
Brucite.....	Idria, Austria	Green	Medium	Do.
	Texas, Pa.	Cream white	do.	Do.
Bustamite.....	Franklin, N. J.	Pink	Weak	Do.
Byssolite. (See tremolite.)				
Cacholong. (See opal.)				
Calamite. (See tremolite.)				
Calcite.....	Cumberland, England	Pink	do.	Do.
	Pribram, Bohemia	do.	Very weak	Do.
	Badlands, S. Dak.	Yellow green	Weak	Do.
	Franklin, N. J.	Red	Strong	Do.
	Alston Moor, England	do.	do.	Do.
Reichite.....	North White River, Wyo.	Pink	Weak	Do.
Oolite.....	Carlsbad, Bohemia	Pale gray	Medium	Do.
Fisolite.....	Franklin, N. J.	Red	Strong	Do.
Manganocalcite.....	Warren, Ariz.	Dark red	Weak	Do.
Cuprocalcite.....	Bleiberg, Austria	Cream white	do.	Do.
Plumbocalcite.....	Franklin, N. J.	None	Zero	Do.
Calcium larsentite.....	do	Yellow	Medium	Do.
Californite. (See idocrase.)				
Cassinite. (See hyalophane.)				
Castorite. (See petalite.)				

Mineral	Locality	Infrared luminescence			Emission wavelength
		Strength	Range of excitation	Maximum of excitation	
Bentonite. (See montmorillonite.)	Muzo, Colombia.	Very strong.	Red through ultraviolet.	Red (ultraviolet)	Short.
Beryl	Kongsberg, Norway.	Medium.	Red through blue.	Red	Do.
	Alexander County, N. C.	Strong.	Red through blue-violet.	do	Very short.
	Fahlun, Sweden.	Very strong.	Red through ultraviolet.	Red (ultraviolet)	Medium.
		Medium.	Red through blue-violet.	Red	Short.
Botryogen:					
Idrizite.	Idria, Austria.	Weak.	Green through blue-violet.	Green through blue-violet	Medium.
Bucite.	Texas, Pa.	Very weak.	Indeterminable.	Indeterminable.	Do.
Bustamite.	Franklin, N. J.	Weak.	Red, green.	Red	Do.
Byssolite. (See tremolite.)					
Cacholong. (See opal.)					
Calamite. (See tremolite.)					
Calcite	Cumberland, England.	do	Green, blue.	Green.	Very short.
	Pribram, Bohemia.	do	Green through blue-violet.	Green, blue.	Very long.
	Badlands, S. Dak.	do	Red through blue-violet.	Red through blue.	Short.
	Franklin, N. J.	do	Red through blue.	Green.	Do.
Reichite.	Alston Moor, England.	Very weak.	Indeterminable.	Indeterminable.	Very short.
Oolite.	North White River, Wyo.	Weak.	Red, green, violet.	Red (violet)	Medium.
Pisolite.	Carlsbad, Bohemia.	Medium.	Red through violet.	do	Do.
Manganocalcite.	Franklin, N. J.	do	do	Red, green, (violet).	Short.
Cuprocalcite.	Warren, Ariz.	Weak.	Red, violet.	Red (violet)	Long.
Plumbocalcite.	Bleiberg, Austria.	Very weak.	Red through violet.	Red through violet.	Very short.
Calcium larsenite.	Franklin, N. J.	Weak.	Red through blue.	Red, green.	Long.
	do	do	Red, green.	Red.	Do.
Californite. (See idocrase.)					
Cassinite. (See hyalophane.)					
Castorite. (See petalite.)					

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Celestine.....	Borate, Calif.....	Cream white.....	Medium.....	Average.
Cerolite. (See saponite.)	Tsumeb, South-west Africa.....	do.....	Weak.....	Do.
Cerussite.....	Davidson's mine, N. C.....	Yellow.....	Medium.....	Bright.
Cervantite.....	Gulzora, New South Wales.....	None.....	Weak.....	Average.
Chalcedony. (See quartz.)	Tolimán, Queretaro, Mexico.....	do.....	do.....	Bright.
Chiasolite. (See andalusite.)	Ivigut, Greenland.....	do.....	Zero.....	Do.
Chiolite.....	Minsk, Ural Mountains, Russia.....	do.....	do.....	Do.
Chlorite. (See cookeite, colearinite.)				
Chromtremolite. (See tremolite.)	Ceylon.....	do.....	do.....	Average.
Chrysoberyl.....	Katharinenburg, Ural Mountains, Russia.....	Red.....	Very weak.....	Do.
Alexandrite.....	Ural Mountains, Russia.....	None.....	Zero.....	Do.
Chrysotile. (See serpentine.)				
Colemanite.....	Furnace Creek, Calif.....	Cream white.....	Weak.....	Do.
Neocolemanite.....	Lang, Calif.....	Yellow.....	Medium.....	Do.
Colearinite.....	Nottingham, Pa.....	Gray brown.....	Very weak.....	Do.
Collyrite. (See allophane.)				
Conifolensite. (See kaolinite.)	Buckfield, Maine.....	None.....	Zero.....	Do.
Cookeite.....				

Mineral	Locality	Infrared luminescence			
		Strength	Range of excitation	Maximum of excitation	Emission wavelength
Celestine	Borate, Calif.	Weak	Red through blue	Red through blue	Short.
Cerolite. (See saponite.)	Tsumeb, South-west Africa	Very weak	Indeterminable	Indeterminable	Medium.
Cerussite	Davidson's mine, N. C.	Weak	Red through violet	Red through blue	Do.
Cervantite	Gulzora, New South Wales	do	Green through blue-violet	Blue	Long.
Chalcedony. (See quartz.)	Tolliman, Queretaro, Mexico.	Medium	do	do	Medium.
Chastolite. (See andalusite.)					
Chiolite	Ivigut, Greenland	do	do	Red, green	Short.
Chlorite. (See cookeite, colerainite.)	Musk, Ural Mountains, Russia.	Weak	Red through blue	Red through blue	Very short.
Chromtremolite. (See tremolite.)					
Chrysoberyl	Ceylon	Very weak	Green, blue	Green, blue	Medium.
Alexandrite	Katherinenburg, Ural Mountains, Russia.	Strong	Red through violet	Red	Short.
	Ural Mountains, Russia.	Medium	Red through blue-violet	Red, green	
Chrysotile. (See serpentine.)					
Colerainite	Furnace Creek, Calif.	Weak	do	Red through blue-violet	Very short.
Neocolemanite	Lang, Calif.	do	Red through violet	Green (violet)	Medium.
Colerainite	Nottingham, Pa.	do	Red	Red	Do.
Collyrite. (See allophane.)					
Confolensite. (See kaolinite.)					
Cookeite	Buckfield, Maine	do	Red, green	do	Do.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Corundum	Rabun County, Ga.	None	Zero	Average.
	Belgrade, Mont.	do	do	Do.
	Amity, N. Y.	Red	Very weak	Do.
	Buck Creek, N. C.	None	Zero	Do.
	Ceylon	do	do	Do.
	do	do	do	Do.
Sapphire		do	do	Do.
Synthetic ruby		do	do	Do.
Creedite	Wagon Wheel Gap, Colo.	Red	Strong	Bright.
Crestmoreite	Crestmore, Calif.	Pale blue	Weak	Do.
Cristobalite	Saplores, Durango, Mexico	Pale gray	do	Average.
Melanophlogite	Girgenti, Sicily	Green	Strong	Do.
Cryolite	Pikes Peak, Colo.	Pale brown	Medium	Bright.
	Ivigut, Greenland	None	Zero	Average.
	do	do	do	Bright.
Cryolithionite	do	do	do	Average.
Cuprite	Wheal Phoenix, Cornwall, England	do	do	
Cuprocaltite. (See calcite.)				
Cuproscheelite. (See cuprotungstite.)				
Cuprotungstite	Tonechi, Mexico	Green	Medium	Do.
Cuproscheelite	La Paz, Mexico	Gray	do	Faint.
Danburite	Danbury, Conn.	Pale brown	Weak	Average.
Datolite	Tadjik, Russia	Cream white	Medium	Do.
Delawarite. (See orthoclase.)				
Demantoid. (See andradite.)				
Deweyite	Newcastle, Del.	Pale ochre	Weak	Bright.
	Delight, Md.	None	Medium	Average.
Gymnite	Fleims, Tyrol	Pale green	do	Bright.
Diallage	Franklin, N. J.	None	Zero	Average.
Diamond	South Africa	do	do	Do.
Carbonado	Brazil	do	do	Bright.

Mineral	Locality	Infrared luminescence			
		Strength	Range of excitation	Maximum of excitation	Emission wavelength
Corundum	Rabun County, Ga.	Strong	Red through blue-violet.	Red	Medium.
	Belgrade, Mont.	Weak	Green, blue	Green	Very short.
	Amity, N. Y.	Strong	Red through blue-violet.	do.	Do.
	Buck Creek, N. C.	Very strong	Red through ultraviolet.	Red (ultraviolet)	Do.
	Ceylon.	Strong	Red through blue-violet.	Green	Do.
	do.	Weak	Green, blue	Green, blue	Medium.
Sapphire.		Very strong	Red through ultraviolet.	Red through blue	Short.
Synthetic ruby				(ultraviolet)	
Creedite	Wagon Wheel Gap, Colo.	Weak	Red through violet.	Red through violet.	Medium.
Crestmoreite	Crestmore, Calif.	do.	Red, violet.	Violet	Do.
Cristobalite	Saplores, Durango, Mexico	Medium	Red through violet.	Violet, red, blue	Long.
Melanophlogite	Girgenti, Sicily	do.	do.	Red (violet)	Medium.
Cryolite	Pikes Peak, Colo.	Weak	Red through blue	Red, green	Short.
	do.	do.	do.	Red through blue	Very short.
Cryolithionite	Ivigut, Greenland	do.	Red, violet.	Violet	Do.
Cuprite	Wheal Phoenix, Cornwall, England.	do.	Red, green.	Red	Very long.
Cuprocalcite. (See calcite.)					
Cuproscheelite. (See cuprotungstite.)					
Cuprotungstite	Tonechi, Mexico.	Medium	Red through blue.	do.	Long.
Cuproscheelite	La Paz, Mexico	Weak	Red, green.	do.	Very long.
Danburite	Danbury, Conn.	do.	Red through blue	do.	Medium.
Datolite	Tadjik, Russia	Medium	Red through violet.	Red (violet)	Short.
Delawarite. (See orthoclase.)					
Demantoid. (See andradite.)					
Deweylite	Newcastle, Del.	do.	do.	Red, green	Do.
	Delight, Md.	do.	Red through blue.	Red	Do.
Gymnite	Fleims, Tyrol	do.	Red through blue-violet.	do.	Medium.
Diallage	Franklin, N. J.	do.	Red through violet.	do.	Do.
Diamond	South Africa	Weak	Green through blue-violet	do.	Do.
Carbonado	Brazil	Medium	Red through blue-violet.	Red, green	Do.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Diaspore.....	Schemnitz, Czechoslovakia.....	None.....	Zero.....	Average.....
Diopside.....	Laurel Creek, Ga.....	Brown.....	Weak.....	Do.....
Melacolite.....	Franklin, N. J.....	None.....	Zero.....	Do.....
Larrovite.....	Sing Sing, N. Y.....	do.....	do.....	Bright.....
Dolomite.....	Baikal Lake, Siberia.....	do.....	do.....	Average.....
	St. Louis, Mo.....	do.....	do.....	Bright.....
	do.....	Brown.....	Weak.....	Do.....
Gurhofite.....	Traversella, Italy.....	Pink.....	do.....	Average.....
Tautoklin.....	Cold Spring, N. Y.....	do.....	Very weak.....	Do.....
Emerald. (See beryl.)	Freiberg, Saxony.....	Pale green.....	Weak.....	Bright.....
Enstatite.....				
Epidote:	Taleville, N. Y.....	None.....	do.....	Average.....
Tawnavite.....				
Ersbyite. (See meionite.)	Myitkyina, Burma.....	Dark red.....	Very weak.....	Do.....
Euclase.....				
Feldspar. (See orthoclase, adularia, microcline, hyalophane, albite, oligoclase, andesine, anorthite.)	Villa Rica, Brazil.....	do.....	Medium.....	Faint.....
Fibrolite. (See sillimanite.)				
Fischerite. (See wavelite.)				
Fluorapatite. (See apatite.)				
Fluorite.....	Corocoro, Bolivia.....	Pale blue.....	Weak.....	Average.....
	Alston Moor, England.....	do.....	Medium.....	Do.....
	St. Louis, Mo.....	Yellow.....	do.....	Do.....
	Clay Center, Ohio.....	do.....	Strong.....	Do.....
	Amelia Courthouse, Va.....	Green.....	Weak.....	Do.....
	Hundholmen, Norway.....	Yellow.....	Medium.....	Do.....
	Northern Norway.....	do.....	do.....	Do.....
Yttriofluorite.....				

Mineral	Locality	Infrared luminescence			
		Strength	Range of excitation	Maximum of excitation	Emission wavelength
Diaspore	Schemnitz, Czechoslovakia	Weak	Red through blue-violet	Red	Medium.
	Laurel Creek, Ga.	do.	Red through blue	Red	Do.
Diopside	Franklin, N. J.	Medium	Red	Red	Do.
Malacolite	Sing Sing, N. Y.	Weak	Red through violet	Red (violet)	Do.
Lawsonite	Baikal Lake, Siberia	Strong	Red through blue-violet	Red, blue	Long.
Dolomite	St. Louis, Mo.	Medium	Red through blue	Red	Short.
	do.	Weak	Red through blue-violet	do.	Medium.
Gurhofite	Traversella, Italy	Very weak	Indeterminable	Indeterminable	Short.
Tautoklin	Cold Spring, N. Y.	Weak	Red, violet	Violet	Medium.
Emerald. (See beryl.)	Freiberg, Saxony	Medium	Red through blue	Red	Do.
Enstatite	Taleville, N. Y.	Weak	Red	Red	Long.
Epidote:					
Tawmawite	Myitkyina, Burma	Medium	Red through blue-violet	do.	Medium.
Ersbyite. (See métonite.)					
Euclase					
Feldspar. (See orthoclase, adularia, microcline, hyalophane, albite, oligoclase, andesine, anorthite.)	Villa Rica, Brazil	Strong	Red, green	do.	Short.
Fibrolite. (See sillimanite.)					
Fischerite. (See wavellite.)					
Fluorapatite. (See apatite.)					
Fluorite	Corocoro, Bolivia	do.	Red through blue-violet	do.	Do.
	Alston Moor, England	Weak	Red	do.	Medium.
	St. Louis, Mo.	Medium	Red through green	do.	Do.
	Clay Center, Ohio	Strong	Red through blue-violet	Red through blue	Short.
	Amelia Courthouse, Va.	Weak	Red through violet	Red	Very short.
	Hundholmen, Norway	Medium	Red through blue-violet	Green, blue	Medium.
Yttriofluorite	Northern Norway	Weak	Green, blue	do.	Do.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Fuchsite. (See muscovite.)				
Garnet. (See grossularite, andradite.)	Ragtown Lake, Nev.	Cream white.	Weak.	Average.
Gaýlussite	St. Peter's Dome, Colo.	Red.	Medium.	Do.
Gearsulite				
Geyselite. (See opal.)	Llallagua, Bolivia.	do.	Very weak.	Do.
Glagerite. (See halloysite.)	do.	None.	Zero.	Do.
Greenockite	Topaz, Calif.	do.	do.	Do.
	Franklin, N. J.	do.	do.	Do.
	Bishopon, Scotland.	do.	do.	Do.
	North Thomson River, British Columbia.	do.	do.	Do.
Grossularite				
Gurhofite. (See dolomite.)	Montmartre, France.	Brown.	Weak.	Do.
Gymnite. (See deweylite.)	Galapagos Islands.	Cream white.	Medium.	Bright.
Gypsum	Lockport, N. Y.	Brown.	Weak.	Do.
	New Almaden, Calif.	do.	do.	Average.
Gyrolite				
Hackmanite. (See sodalite.)	Borax Lake, Calif.	Cream white.	Medium.	Bright.
Halite	Stazunia, Poland.	Yellow.	do.	Average.
	Pala, Calif.	Brown.	Weak.	Do.
Halloysite	Bedford, Ind.	Gray.	Medium.	Bright.
	do.	Cream white.	Weak.	Do.
Indianaite	Bergnersreuth, Bavaria.	None.	Zero.	Average.
Glagerite	Helgøen, Norway.	Orange pink.	Weak.	Do.
Hambergite	Searles Lake, Calif.	None?	Zero.	Do.
Hanksite				

Mineral	Locality	Infrared luminescence			Emits on wavelength
		Strength	Range of excitation	Maximum of excitation	
Fuchsite. (See muscovite.)					
Garnet. (See grossularite, andradite.)					
Gaylussite	Ragtown Lake, Nev.	Medium	Red through blue-violet	Red through blue	Short.
Gearschuttite	St. Peter's Dome, Colo.	do.	Red through violet	Red (violet)	Do.
Geyserite. (See opal.)					
Glagerite. (See halloysite.)					
Greenockite	Llallagua, Bolivia	Strong	do.	Green, blue	Medium.
	do.	Weak	Red through blue-violet	do.	Do.
	Topaz, Calif.	do.	Green, blue	do.	Do.
	Franklin, N. J.	Medium	Green through blue-violet	Blue, blue-violet	Do.
	Bishopton, Scotland	Strong	Red through blue	Red, green	Do.
	North Thomson River, British Columbia.	Weak	Red, blue, blue-violet	Red	Short.
Grossularite					
Gurhofite. (See dolomite.)					
Gymnite. (See deweyllite.)					
Gypsum	Montmartre, France	Very weak	Red through blue	Red through blue	Medium.
	Galapagos Islands	Medium	Red through blue-violet	Red through blue-violet	Do.
	Lockport, N. Y.	Weak	Red through violet	Red through violet	Do.
	New Almaden, Calif.	do.	Red through blue-violet	Red through blue-violet	Do.
Gyrolite					
Hackmanite. (See sodalite.)					
Halite	Borax Lake, Calif.	do.	Indeterminable	Indeterminable	Short.
	Stazunia, Poland	Medium	Red through violet	Red through blue-violet	Medium.
	Pala, Calif.	do.	Red through blue-violet	Red, green	Short.
Halloysite	Bedford, Ind.	Weak	do.	do.	Medium.
		Medium	Red, green, violet	Red (violet)	Short.
Indianite	Bergnersreuth, Bavaria	do.	do.	do.	Do.
Glagerite	Helgaaen, Norway	Weak	Blue-violet through ultraviolet	Ultraviolet	Medium.
Hambergitte					
Hanksite	Searles Lake, Calif.	Very weak	Indeterminable	Indeterminable	Do.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Harringtonite. (See thomsonite.)	Laacher See, Germany	None	Zero	Average.
Haunite	Franklin, N. J.	do	do	Do.
Hedyphane	do	Cream white	Weak	Do.
Heminorphite:				
Vanuxemite	Stirling Hill, N. J.	Pale gray	Medium	Do.
Hexagonite. (See tremolite.)				
Hiddenite. (See spodumene.)				
Hornblende:				
Pargasite	Rosie, N. Y.	None	Zero	Do.
	Edenville, N. Y.	do	do	Do.
	Lang, Calif.	Red brown	Weak	Do.
	Wentworth, Nova Scotia	Cream white	do	Do.
Howlite				
Hyalophane:				
Cassinite	Media, Pa.	None	Zero	Do.
	Wanlockhead, Scotland	do	do	Do.
Hydrocerussite				
Hydronephelite. (See natrolite.)				
Hydrophane. (See opal.)				
Hydrotalcite				
Iddingsite. (See serpentine.)	Somerville, N. Y.	do	do	Do.
Idocrase:				
Californite				
	Lindsay, Calif.	do	do	Do.
	North Thompson River, British Columbia	do	do	Do.
Idrizite. (See botryogen.)				
Indianite. (See halloysite.)				

Mineral	Locality	Infrared luminescence			Emission wavelength
		Strength	Range of excitation	Maximum of excitation	
Harringtonite. (See thomsonite.)	Leacher See, Germany	Very weak	Indeterminable	Indeterminable	Short.
Haunite.	Franklin, N. J.	Medium	Red through blue	Red	Long.
Hedyphane.	do.	Very weak	Indeterminable	Indeterminable	Indeterminable.
Hemimorphite:					
Vanuxemite.	Stirling Hill, N. J.	Medium	Red, violet.	Red	Short.
Hexagonite. (See tremolite.)					
Hiddenite. (See spodumene.)					
Hornblende:					
Pargasite.	Rossie, N. Y.	Strong	Red through blue-violet.	do.	Medium.
	Edenville, N. Y.	Medium	Red, blue.	do.	Short.
Howlite	Lang, Calif.	Weak	Red through blue.	Green	Medium.
	Wentworth, Nova Scotia	Medium	Red through blue-violet.	Red through blue.	Short.
Hyalophane:					
Cassinite.	Media, Pa.	do.	Red, green.	Red	Medium.
Hydrocerussite.	Wanlockhead, Scotland	Weak	Red through blue.	Red through blue	Do.
Hydronephelinite. (See natrolite.)					
Hydrophane. (See opal.)					
Hydrotalcite.					
Iddingsite. (See serpentine.)	Somerville, N. Y.	do.	do.	Green	Do.
Idocrase:					
Californite.	Lindsay, Calif.	Very strong	Red through blue-violet.	Red	Short.
	North Thompson River, British Columbia.	Medium	Red through violet.	Red (violet)	Medium.
Idrizite. (See botryogen.)					
Indianite. (See halloysite.)					

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Jadeite.....	Magong, Burma.....	None.....	Zero.....	Average.
Jurupaite.....	Buena Vista de Cueller, Durango, Mexico.	do.....	do.....	Do.
Kaolinite:	Tenochtitlan, Vera Cruz, Mexico.....	do.....	do.....	Do.
Lithomarge.....	Crestmore, Calif.....	Blue gray.....	Medium.....	Do.
Confolensite.....	Banat, Hungary.....	Pale brown.....	do.....	Do.
Kyanite.....	Confolens, France.....	Cream white.....	do.....	Do.
	Litchfield, Conn.....	None.....	Zero.....	Do.
	Hurricane Mountain, N. C.....	do.....	do.....	Do.
	Hillswick, Scotland.....	do.....	do.....	Do.
	St. Gotthard, Scotland.....	do.....	do.....	Do.
Rhaetizite.....	Pfisch, Tyrol.....	Cream white.....	Very weak.....	Do.
Lanarkite.....	Leadhills, Scotland.....	Pale yellow.....	Medium.....	Do.
Laubanite. (See natrolite.)				
Laumontite:				
Leonhardite.....	Zillerthal, Tyrol.....	Cream white.....	Weak.....	Do.
Retzite.....	Vivero, Lugo, Spain.....	None.....	Zero.....	Do.
Lavrovite. (See diopside.)				
Lazulite.....	Horsjoberg, Sweden.....	do.....	do.....	Do.
Leadhillite.....	Leadhills, Scotland.....	Brown.....	Weak.....	Do.
Leelite. (See orthoclase.)				
Lennite. (See orthoclase.)				
Leonhardite. (See laumontite.)				
Lepidolite.....	Elba.....	None.....	Zero.....	Bright.
Leucophanite.....	Laven, Norway.....	Pale pink.....	Weak.....	Do.
Leucophoenicite.....	Franklin, N. J.....	None.....	Zero.....	Average.

Mineral	Locality	Infrared luminescence			
		Strength	Range of excitation	Maximum of excitation	Emission wavelength
Jadeite.....	Magoung, Burma. Buena Vista de Cueller, Durango, Mexico. Tenochtitlan, Vera Cruz, Mexico.	Very strong. Strong	Red through violet. Red through blue-violet.	Red (violet). Red.	Medium. Do.
Jasper. (See quartz.)		Weak.....	Red, blue, blue-violet.....	do.....	Do.
Jurupaite.....	Crestmore, Calif.....	Strong.....	Red through blue, violet.....	Green (violet).....	Do.
Kaolinite:					
Lithomarge.....	Banat, Hungary.....	Medium.....	do.....	Red.....	Short.
Confonsinite.....	Confolens, France.....	do.....	Red, green, violet.....	Violet.....	Do.
Kyanite.....	Litchfield, Conn.....	Strong.....	Red through violet.....	Red.....	Medium.
	Hurricane Mountain, N. C.....	do.....	do.....	do.....	Do.
	Hillswick, Scotland.....	Weak.....	Red, green.....	Red, green.....	Do.
	St. Gotthard, Scotland.....	Medium.....	Red through violet.....	Red (violet).....	Short.
Rhaetizite.....	Pfätsch, Tyrol.....	do.....	do.....	do.....	Medium.
Lanarkite.....	Leadhills, Scotland.....	Weak.....	Indeterminable.....	Indeterminable.....	Do.
Laubanite. (See natrolite.)					
Laumontite:					
Leonhardtite.....	Zillerthal, Tyrol.....	do.....	Red through violet.....	Green.....	Do.
Retzite.....	Vivero, Lugo, Spain.....	Medium.....	Red, green.....	Red.....	Do.
Lavrovite. (See diopside.)					
Lazulite.....	Horsjöberg, Sweden.....	do.....	do.....	do.....	Do.
Leadhillite.....	Leadhills, Scotland.....	Weak.....	Red through violet.....	Red through blue (violet).....	Do.
Leelite. (See orthoclase.)					
Leemilite. (See orthoclase.)					
Leonhardtite. (See laumontite.)					
Leptodolite.....	Elba.....	Medium.....	Red through blue.....	Red, green.....	Very short.
Leucophanite.....	Laven, Norway.....	do.....	do.....	Red.....	Very long.
Leucophoenicite.....	Franklin, N. J.....	Very weak.....	Red.....	do.....	Indeterminable.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Lithomarge. (See kaolinite.)				
Lucianite. (See talc.)				
Magnesite.....	Delight, Md.	Pale green.....	Weak.....	Bright.
Baudisserite.....	Hoboken, N. J.	Cream white.....	do.....	Average.
Malthactite. (See allophane.)	Baudissero, Italy	Cream gray.....	do.....	Do.
Manganapatite. (See apatite.)				
Manganocalcite. (See calcite.)				
Marshite.....				
Matlockite.....	Chuquicamata, Chile	Red.....	Medium.....	Do.
Meionite:	Broken Hill, New South Wales	do.....	do.....	Faint.
Ersbyite.....	Derbyshire, England	Yellow.....	do.....	Average.
Stroganovite.....	Cromford, England	Brown.....	do.....	Do.
Melacolite. (See diopside.)	Pargas, Finland	Pale blue.....	Weak.....	Do.
Melanophlogite. (See cristobalite.)	Baikal Lake, Siberia	Cream white.....	do.....	Do.
Mellite.....				
Mesolite.....	Antern, Saxony	Ochre.....	do.....	Do.
Messelite. (See anapaite.)	Tula, Russia	Brown.....	Very weak.....	Do.
Metaxoite. (See serpentine.)	Golden, Colo.	Green.....	Medium.....	Do.
Mica. (See muscovite, lepidolite, taeniolite.)	Belfast, Ireland	Cream white.....	Very weak.....	Bright.

Mineral	Locality	Infrared luminescence			Emission wavelength
		Strength	Range of excitation	Maximum of excitation	
Lithomarge. (See kaolinite.)					
Lucianite. (See talc.)					
Magnesite	Delight, Md	Medium	Red through blue	Red, green	Short.
Baudisserite	Hoboken, N. J.	Weak	do	Red through blue	Very short.
Malthactite. (See allophane.)	Baudissiero, Italy	do	Red, violet	Violet	Medium.
Manganapatite. (See apatite.)					
Manganocalcite. (See calcite.)					
Marshite					
Matlockite	Chuquicamata, Chile	Weak	Blue-violet, violet	do	Do.
Meionite	Broken Hill, New South Wales	do	Blue through ultraviolet	Blue-violet, violet (ultraviolet)	Do.
Ersbyite	Derbyshire, England	Medium	Green through violet	Blue-violet (violet)	Do.
Stroganovite	Cromford, England	Weak	Blue, blue-violet	Blue, blue-violet	Do.
Melaccolite. (See diopside.)					
Melanophlogite. (See cristobalite.)	Pargas, Finland	Weak	Red, green	Red	Medium.
Melite	Baikal Lake, Siberia	do	Red	do	Do.
Mesolite					
Messelite. (See anapaite.)	Antem, Saxony	do	Green, blue	Green, blue	Very short.
Metaxoite. (See serpentine.)	Tula, Russia	Medium	Red through blue	Red	Do.
Mica. (See muscovite, lepidolite, taeniolite.)	Golden, Colo.	Weak	do	Red through blue	Medium.
	Belfast, Ireland	Medium	Red through blue-violet	Red	Short.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Microcline.....	Pikes Peak, Colo.....	None.....	Zero.....	Average.
Mimetite.....	do.....	do.....	do.....	Do.
Molybdochalite. (See sodalite.)	Fianarantsoa, Madagascar.....	do.....	do.....	Do.
Montmorillonite.....	Tsumeb, South-West Africa.....	do.....	do.....	Do.
Steargillite.....	Paris, Maine.....	Pink.....	Weak.....	Do.
Bentonite.....	Glen Riddle, Pa.....	Gray.....	Medium.....	Do.
Stevensite.....	Montmorillon, France.....	Dark red.....	Weak.....	Bright.
Montrondite.....	Yamagata Prefecture, Japan.....	Pink.....	do.....	Do.
Moonstone. (See orthoclase.)	West Paterson, N. J.....	Cream white.....	Medium.....	Average.
Mooreite.....	Terlingua, Tex.....	None.....	Zero.....	Do.
Muscovite.....	Stirling Hill, N. J.....	Red.....	Strong.....	Do.
Fuchsite.....	Brevard, N. C.....	None.....	Zero.....	Do.
Natrolite.....	Steinbruch, Silesia.....	White.....	Medium.....	Do.
Laubauite.....	Brevig, Norway.....	Pink.....	do.....	Do.
Hydronephelite.....	Val di Noto, Sicily.....	Peach pink.....	Weak.....	Do.
Neocolemanite. (See colemanite.)	Kirovsk, U. S. S. R.....	None.....	Zero.....	Do.
Nepheline.....	Clark's Cove, Va.....	Pale gray.....	Medium.....	Bright.
Nitrate salts.....	Crestmore, Calif.....	Pale blue.....	Weak.....	Average.
Okenite.....	Godhaven, Greenland.....	Cream white.....	do.....	Do.
Oligoclase.....	Fine, N. Y.....	None.....	Zero.....	Do.
Omphacite. (See augite.)	Mitchell County, N. C.....	Buff.....	Weak.....	Do.
Onite. (See calcite.)				

Mineral	Locality	Infrared luminescence			Emission wavelength
		Strength	Range of excitation	Maximum of excitation	
Microcline	Pikes Peak, Colo. do. Fianarantsoa, Madagascar Tsumeb, South-West Africa.	Weak Medium do Weak	Red through violet. Red through blue-violet. Red Blue through violet.	Violet Red do Blue-violet	Long. Do. Medium. Do.
Mimetite					
Molybdosodalite. (See sodalite.)					
Montmorillonite	Paris, Maine Glen Riddle, Pa. Montmorillon, France. Yamagata Prefecture, Japan.	Strong Weak Medium do	Red through blue. Red, green, violet. do do	Red Red (violet) do do	Short. Medium. Short. Do.
Steargillite					
Bentonite					
Stevensite	West Paterson, N. J.	Strong	Red through blue-violet.	Red	Do.
Montroydite	Terlingua, Tex.	Medium	Red	do	Long.
Moonstone. (See orthoclase.)					
Mooreite	Stirling Hill, N. J.	do	Red through violet	Green (violet)	Short.
Muscovite:					
Fuchsite	Brevard, N. C.	Strong	Green, blue	Green	Very short.
Natrolite:					
Laubaniite	Steinbruch, Silesia.	Medium	Red, green, violet	Red (violet)	Short.
Hydronephelie	Brevig, Norway	Weak	Red	Red	Medium.
Neocolemanite. (See colemanite.)					
Nepheline	Val di Noto, Sicily	Very weak	Red through violet	Red through violet	Indeterminable.
	Kirovsk, U. S. S. R.	Weak	Red, green	Red	Long.
Nitrate salts	Clark's Cove, Va.	do	Red, green, violet	Red (violet)	Medium.
Okenite	Crestmore, Calif.	do	Red through blue-violet	Green	Do.
	Godhaven, Greenland	do	do	Red through blue-violet	Do.
	Fine, N. Y.	do	Red through violet	Red (violet)	Do.
Oligoclase	Mitchell County, N. C.	do	Red through blue-violet	Green	Do.
Omphacite. (See augite.)					
Oolite. (See calcite.)					

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Opal	Queretaro, Mexico	Pale yellow	Weak	Average.
	Dubnik, Czechoslovakia	White	Very weak	Do.
	Faroe Islands	do.	do.	Bright.
	Divide, Colo.	Pale green	Weak	Do.
Cacholong	Rudit, Moravia	Cream white	do.	Do.
Hydrophane	Veresvagas, Hungary	do.	do.	Bright.
Geysertite	Yellowstone, Wyo.	Pale yellow	Medium	Average.
Silicified Wood	Granger Wyo.	Dark orange	Very weak	Do.
Tabasheer	Calcutta, India	Pale brown	Weak	Do.
Orthoclase	New Castle County, Del.	Olive green	do.	Do.
	Auburn, Maine	None	Zero	Do.
Moonstone	Ceylon	Red	Weak	Do.
Leelite	Chester County, Pa.	Pale yellow	Medium	Do.
Lennilite	Lenni, Pa.	Gray green	do.	Do.
Delawarite	do.	Red	Weak	Do.
Parahopelite	Salmo, British Columbia	Pale orange	do.	Do.
Pargasite. (See hornblende.)	Great Notch, N. J.	Cream white	do.	Bright.
Pectolite	Thetford, Quebec	do.	do.	Average.
	Landalfoot, Scotland	do.	do.	Do.
Peristerite. (See albite.)	Greenwood, Maine	Buff	do.	Do.
Petalite	Elba	None	Zero	Do.
Castorite	Derbyshire, England	Yellow	Medium	Do.
Phosgenite	Montepioni, Sardinia	do.	Weak	Do.
Phosphorite. (See apatite.)	Searles Lake, Calif.	None	Zero	Bright.
Prsronite				
Piscolite. (See calcite.)	Tim Mountain, Custer, S. Dak.	Cream white	Very weak	Do.
Plumbocalcite. (See calcite.)	Ryan, Calif.	None	Zero	Do.
Pollucite				
Probertite				

Mineral	Locality	Infrared luminescence			Emission wavelength
		Strength	Range of excitation	Maximum of excitation	
Opal	Queretaro, Mexico	Weak	Red through blue	Red	Very short.
	Dubnik, Czechoslovakia	do	do	do	Do.
	Faroe Islands	do	Green	Green	Do.
	Divide, Colo.	do	Red through blue	Red through blue	Medium.
	Ruditz, Moravia	do	do	do	Do.
Cacholong	Veresvagas, Hungary	do	Red	Red	Do.
Hydrophane	Yellowstone, Wyo.	Medium	Red through violet	Red (violet)	Long.
Geyserite	Granger, Wyo.	Strong	Red through blue	Red through blue	Medium.
Silicified Wood	Calcutta, India	do	Red through violet	Red	Do.
Tabasheer	New Castle County, Del.	Medium	Red through blue	do	Short.
Orthoclase	Auburn, Maine	Very weak	Red, green, violet	Red (violet)	Medium.
	Ceylon	Weak	Red, violet	do	Do.
Moonstone	Chester County, Pa.	Medium	Red, green, blue, violet	do	Short.
Leelite	Lenni, Pa.	do	Red, green, violet	do	Do.
Lennilite	do	Weak	do	do	Medium.
Delawarite	Salmo, British Columbia	do	do	do	Do.
Parahopette					
Pargasite. (See hornblende.)					
Pectolite					
	Great Notch, N. J.	do	Red through blue	Red through blue	Very short.
	Thetford, Quebec	do	Red through blue-violet	Red	Do.
	Landalfoot, Scotland	do	Red through blue	Red through blue	Medium.
Peristerite. (See albite.)					
Petalite					
Castorite	Greenwood, Maine	Weak	Red, green	Red, green	Very short.
Phosgenite	Elba	Medium	Green, blue	Green, blue	Medium.
	Derbyshire, England	Very weak	Blue-violet, violet	Violet	Indeterminable.
	Monteponi, Sardinia	Weak	Blue through violet	Blue through violet	Short.
Phosphorite. (See apatite.)					
Prisonite	Searles Lake, Calif.	Very weak	Red	Red	Medium.
Pisolite. (See calcite.)					
Plumbocalcite. (See calcite.)					
Pollucite	Tim Mountain, Custer, S. Dak.	Medium	Red through violet	Red through blue-violet	Short.
Proberite	Ryan, Calif.	Weak	Red, violet	Violet	Medium.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Pseudosmaragd. (See beryl.)				
Pyromorphite	Cumberland, England	Brown	Very weak	Average.
	Phoenixville, Pa.	do	do	Do.
Pyrrophyllite:				
Agalmatolite	China	Cream white	Weak	Do.
Pyroxene	Franklin, N. J.	None	Zero	Faint.
(See also diopside, spodumene, jadeite, diallage, enstatite.)				
Quartz:				
Chalcedony	Tampa, Fla.	Yellow	Weak	Average.
	Guajuato, Mexico	do	do	Do.
	Death Valley, Calif.	do	Medium	Do.
Agate	Chagres River, Canal Zone	do	do	Bright.
	San Luis Potosi, Mexico	Brown	Very weak	Average.
Jasper	San Francisco, Calif.	do	Weak	Do.
	Bridger Basin, Wyo.	None	Zero	Do.
Quincite. (See sepiolite.)				
Razoumowskyn. (See allophane.)				
Reichite. (See calcite.)				
Retzite. (See laumontite)				
Rhaetizite. (See kyanite.)				
Rhodochrosite				
Rhodophosphite. (See apatite.)				
Ruby. (See corundum.)				
Saccharite. (See andesine.)				
	Marquette County, Mich.	Pink	Medium	Do.

Mineral	Locality	Infrared luminescence			Emission wavelength
		Strength	Range of excitation	Maximum of excitation	
Pseudosmaragd. (See beryl.)	Cumberland, England.	Medium	Red through blue	Red	Long.
Pyromorphite	Phoenixville, Pa.	Weak	Red, green	do.	Do.
Pyrophyllite:	China	do.	Red through blue	Red, green	Medium.
Pyroxene	Franklin, N. J.	Weak	Red	Red	Medium.
(See also diopside, spodumene, jadeite, diallage, enstatite.)					
Quartz:					
Chalcedony	Tampa, Fla.	Medium	Red, green	do.	Short.
	Guanajuato, Mexico.	Weak	Red	do.	Do.
	Death Valley, Calif.	do.	Red, green	Red, green	Medium.
Agate	Chagres River, Canal Zone	do.	Red	Red	Indeterminable.
	San Luis Potosi, Mexico.	Medium	Red through blue-violet	Red, green	Short.
Jasper	San Francisco, Calif.	Weak	Red, green	do.	Medium.
	Bridger Basin, Wyo.	Medium	Red through blue-violet	Red through blue-violet	Do.
Quincite. (See sepiolite.)					
Razoumovskyn. (See allophanes.)					
Reichite. (See calcite.)					
Retzite. (See laumontite.)					
Rhaetizite. (See kyanite.)					
Rhodochrosite	Marquette County, Mich.	Weak	Green, blue	Green, blue	Very short.
Rhodophosphite. (See apatite.)					
Ruby. (See corundum.)					
Saccharite. (See andesine.)					

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Saponite: Cerolite.		Yellow	Weak	Average.
Sapphire. (See corundum.)				
Saussurite. (See zoisite.)				
Seapolite.				
Scheelite	Bolton, Mass	Cream white	do	Do.
	Arendal, Norway	Red	Very weak	Do.
	Greenville, Quebec	Yellow	Strong	Do.
	Mohave Desert, Calif	Pale yellow	Medium	Do.
	Dragoon Mountains, Ariz	Pale brown	do	Bright.
	Atolia, Calif	White	do	Do.
	Carrock Fell, England	Gray blue	Weak	Average.
Scheelite. (See stolzite.)				
Selenite. (See gypsum.)				
Selensulfur. (See sulfur.)				
Senarmonite	Sonora, Mexico	None	Zero	Do.
Sepiolite	Bare Hills, Md	do	do	Bright.
	North Clay City, Nev	White	Weak	Average.
Quincite	Cher, France	Pale gray	do	Do.
Serpentine	Montville, N. J.	Pink	do	Bright.
Metaxite	Crestmore, Calif	Pale green	Medium	Average.
Chrysotile	New Haven, Conn	None	Zero	Bright.
Iddingsite	Conejos, Colo	Yellow	Weak	Average.
(See also saponite, deweylite.)				
Silicified wood. (See opal.)				
Sillimanite:				
Fibrolite	Paris, Maine	Red	do	Do.
Smithsonite	Marion County, Ga	Brown	Very weak	Do.
	Aiston, England	Rose red	Weak	Do.
	Musua, Sardinia	Brown	do	Do.

Mineral	Locality	Infrared luminescence			Emission wavelength
		Strength	Range of excitation	Maximum of excitation	
Saponite: Cerolite	-----	Weak	Red through blue-violet	Red	Medium.
Sapphire. (See corundum.)	-----	-----	-----	-----	-----
Saussurite. (See zoisite.)	-----	-----	-----	-----	-----
Scapolite	Bolton, Mass.----- Arendal, Norway----- Greenville, Quebec----- Mohave Desert, Calif----- Dragoon Mountains, Ariz----- Atolia, Calif.----- Carrock Fell, England-----	do----- do----- Medium----- Strong----- Medium----- Weak----- Medium-----	Red through blue----- Red through blue-violet----- Blue through ultraviolet----- Red through blue----- Red, green----- Red through violet----- Red, green-----	do----- Green----- Violet (ultraviolet)----- Red----- do----- Red (violet)----- Red-----	Very short. Do. Short. Very long. Do. Do. Medium.
Scheelite. (See stolzite.)	-----	-----	-----	-----	-----
Selenite. (See gypsum.)	-----	-----	-----	-----	-----
Selensulfur. (See sulfur.)	-----	-----	-----	-----	-----
Senarmonite.	Sonora, Mexico.-----	Medium-----	Green through blue-violet	Green, blue-----	Medium.
Sepiolite.	Bare Hills, Md.----- North Clay City, Nev----- Cher, France----- Montville, N. J.----- Crestmore, Calif----- New Haven, Conn----- Conejos, Colo.-----	do----- Weak----- do----- do----- Medium----- Weak----- do-----	Red through blue----- do----- Red, violet----- Red, green, violet----- Red, green----- Red through blue----- do-----	Red----- Red through blue----- Red (violet)----- do----- Red----- Red through blue----- Red, green-----	Medium. Short. Do. Medium. Do. Short. Medium. Do.
Quincite.	-----	-----	-----	-----	-----
Serpentine.	-----	-----	-----	-----	-----
Metaxite.	-----	-----	-----	-----	-----
Chrysotile.	-----	-----	-----	-----	-----
Iddingsite.	-----	-----	-----	-----	-----
(See also saponite, deweylite.)	-----	-----	-----	-----	-----
Silicified wood. (See opal.)	-----	-----	-----	-----	-----
Sillimanite:	Paris, Maine.-----	do-----	Red through blue, violet	Red (violet)-----	Do.
Fibrolite.	Marion County, Ga.-----	Weak-----	Blue, blue-violet-----	Blue, blue-violet-----	Long.
Smithsonite.	Alston, England----- Musua, Sardinia-----	do----- do-----	Red through blue-violet----- Blue-----	Red through blue-violet----- Blue-----	Medium. Short.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Sodalite	Vesuvius, Italy	Pink	Weak	Average.
Molybdosodalite	Monte Somma, Italy	do.	do.	Do.
Hackmanite	do.	Orange	do.	Do.
Solfaterite. (See alunogen.)	Magnet Cove, Ark.	Dark red	Medium	Bright.
Sphalerite	Kola, Russia	Pink	do.	Average.
	Kremmling, Colo.	None	Zero	Do.
	Oruro, Bolivia	do.	do.	Do.
	Cherokee County, Kans.	Pink	Weak	Bright.
	Rodna, Transylvania	None	Zero	Faint.
	Tsumeb, South-West Africa	Orange	Medium	Average.
	Banner district, Idaho	Red	Weak	Do.
Sphene	Tavetsch, Switzerland	None	Zero	Do.
Spinel	Ceylon	Red	Weak	Do.
	Sparta, N. J.	do.	Very weak	Do.
Spodumene	Taos County, N. M.	Cream white	Weak	Do.
Hiddenite	Hiddenite, N. C.	None	Zero	Do.
Steargillite. (See montmorillonite.)				
Stearite. (See talc.)				
Stevensite. (See montmorillonite.)				
Stibianite. (See stibiconite.)				
Stibiconite	Empire district, Nev.	do.	do.	Do.
Stibianite	Potosi, Bolivia	do.	do.	Do.
Stolzite				
Scheelite	Altenberg, Saxony	do.	do.	Do.
Strogonovite. (See meionite.)				
Strontianite	Strontian, Scotland	Olive green	Weak	Do.
Sulfur				
Selensulfur	Cianciana, Italy	None	Zero	Do.

Mineral	Locality	Infrared luminescence			
		Strength	Range of excitation	Maximum of excitation	Emission wavelength
Sodalite	Vesuvius, Italy	Weak	Blue through violet	Blue through violet	Short.
Molybdosodalite Hackmanite	Monte Somma, Italy	do	Red	Red	Do.
	Magnet Cove, Ark	Medium	Blue through violet	Blue through violet	Do.
	do	do	do	Violet	Medium.
	Kola, Russia	do	do	do	Short.
Solfaterite. (See alunogen.)					
Sphalerite	Kremmling, Colo.	do	Red through blue-violet	Red through blue-violet	Long.
	Oruro, Bolivia	Weak	do	Red	Do.
	Cherokee County, Kans.	do	Green	Green	Short.
	Rodna, Transylvania	do	Green through blue-violet	Green through blue-violet	Long.
	Tsumeb, South-West Africa	Very weak	Blue, blue-violet	Blue, blue-violet	Medium.
	Banner district, Idaho	Strong	Red through violet	Red through blue	Long.
Sphene	Tavetsch, Switzerland	Weak	Red through blue-violet	Red, blue	Medium.
Spinel	Ceylon	Medium	do	Red, green	Very short.
	Sparta, N. J.	Strong	do	Green	Short.
Spodumene	Taos County, N. M.	Weak	Red through violet	Red through blue (violet)	Medium.
Hiddenite	Hiddenite, N. C.	Strong	do	Red	Do.
Steargillite. (See montmorillonite.)					
Steatite. (See talc.)					
Stevensite. (See montmorillonite.)					
Stibianite. (See subimonite.)					
Stibiconite	Empire district, Nev.	Medium	Green, blue	Green, blue	Long.
Stibianite	Potosi, Bolivia	do	Red, green, violet	Red (violet)	Short.
Stolzite	Altenberg, Saxony	Weak	Red, green	Red	Long.
Scheelite					
Stroganovite. (See meionite.)					
Strontianite	Strontian, Scotland	Very weak	Green, blue	Green, blue	Very short.
Sulfur	Cianciana, Italy	do	Red through blue	Red through blue	Medium.
Selensulfur					

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Susselite.....	Franklin, N. J.....	None.....	Zero.....	Bright.
Szechenyiite. (See arvedsonite.)				
Tabasheer. (See opal.)				
Taeniolite.....	Magnet Cove, Ark.....	Pink.....	Weak.....	Do.
Talc.....	Edwards, N. Y.....	Cream white.....	do.....	Average.
	Manhattan, Nev.....	None.....	Zero.....	Do.
	Sonora, Mexico.....	Gray.....	Very weak.....	Do.
	Villar de Puercio, Spain.....	Blue gray.....	Medium.....	Bright.
Steatite.....				
Lucianite.....				
Tautoklin. (See dolomite.)				
Tawmawite. (See epidote.)				
Terlinguaite.....	Terlingua, Tex.....	Red.....	Very weak.....	Average.
Thomsonite.....	Kandern, Bohemia.....	Pale brown.....	do.....	Bright.
Harringtonite.....	Belfast, Ireland.....	do.....	do.....	Do.
Thulite. (See zoisite.)				
Topaz.....				
	Minas Geraes, Brazil.....	Brown.....	do.....	Do.
	Villa Rica, Brazil.....	do.....	Weak.....	Do.
	Scheekenstein, Saxony.....	None.....	Zero.....	Do.
Tourmaline.....	Franklin, N. J.....	Brown.....	Weak.....	Do.
	King's Bridge, N. J.....	Green.....	do.....	Faint.
	St. Marcel, Italy.....	Cream white.....	do.....	Bright.
Tremolite.....	Stirling Hill, N. J.....	Pale brown.....	Very weak.....	Average.
	Lee, Mass.....	Green.....	Weak.....	Do.
	Outokumpo, Finland.....	None.....	Zero.....	Do.
Chromtremolite.....	Edwards, N. Y.....	Cream white.....	Weak.....	Do.
Hexagonite.....	Canaan, Conn.....	Pale yellow.....	Medium.....	Do.
Calamite.....	Johns Mansville Mines, Quebec.....	Orange.....	Weak.....	Do.
Byssolite.....		Gray.....	do.....	Do.
Tidymite.....	Durango, Mexico.....	None.....	Zero.....	Do.
Trimerite.....	Langban, Sweden.....	Cream white.....	Weak.....	Do.
Ulexite.....	Mount Blanco, Calif.....	Green.....	Very weak.....	Bright.
Valentinite.....	Constantine, Algiers.....			Average.

Mineral	Locality	Infrared luminescence			
		Strength	Range of excitation	Maximum of excitation	Emission wavelength
Sussexite	Franklin, N. J.	Weak	Red through blue	Violet	Medium.
Szechenyite. (See arfvedsonite.)	Magnet Cove, Ark.	do	Red, green, violet	Red (violet)	Short.
Tabasheer. (See opal.)	Edwards, N. Y.	do	Red through blue	Red through blue	Medium.
Taeniolite	Manhattan, Nev.	Medium	do	Red	Do.
Talc	Sonora, Mexico	Weak	Red, green	Red, green	Do.
Steatite	Villar de Puercos, Spain	Medium	Red, green, violet	Violet	Short.
Lucianite					
Tautoklin. (See dolomite.)					
Tawmawite. (See epidote.)					
Terlingualite	Terlingua, Tex.	Very weak	Green, blue	Green, blue	Medium.
Thomsonite	Kandern, Bohemia	Medium	Red through blue-violet	Red, green	Short.
Harringtonite	Belfast, Ireland	do	Red through blue	Red	Medium.
Thulite. (See zoisite.)					
Topaz	Minas Geraes, Brazil	Strong	Red through violet	Red, green	Short.
	Villa Rica, Brazil	Medium	Red through blue-violet	do	Do.
	Scheckenstein, Saxony	do	do	do	Do.
	Franklin, N. J.	do	Red through violet	Red	Medium.
	King's Bridge, N. J.	Very weak	Red	do	Do.
	St. Marcel, Italy	Weak	Red through blue-violet	do	Do.
	Stirling Hill, N. J.	Strong	do	do	Short.
	Lee, Mass.	Weak	Red, green	Red, blue	Medium.
	Outokumpo, Finland	do	Red, blue	Red	Short.
Chromtremolite	Edwards, N. Y.	do	Red through blue-violet	Green, blue	Medium.
Hexagonite	Canaan, Conn.	do	do	Red, blue	Medium.
Calamite	Johns Mansville Mines, Quebec.	Medium	Red through violet	Red through blue (violet)	Do.
Byssolite					Short.
Tidymite	Durango, Mexico	Weak	Red through violet	Red (violet)	Very long.
Trimerite	Langban, Sweden	Strong	Green through blue-violet	Green, blue	Long.
Ulexite	Mount Blanco, Calif.	Weak	Red through blue-violet	Red, green	Medium.
Valentinite	Constantine, Algiers	do	Red, green	do	Do.

TABLE 4.—*Characteristics of infrared luminescence in selected mineral specimens—Continued*

Mineral	Locality	Visible fluorescence		Infrared reflection
		Color	Intensity	
Valleite. (See anthophyllite.)	Yuma County, Ariz.	None	Zero	Average.
Vanadinite	Tucson, Ariz.	do	do	Do.
Vanuxemite. (See hemimorphite.)				
Wavellite	Llallagua, Bolivia	Green	Weak	Do.
	Barnstable, England	do	Medium	Do.
Fischerite	Hungary	do	Weak	Do.
Willemite	Sussex County, N. J.	do	Medium	Bright.
Wollastonite	Chelsea, Ontario	Brown	Weak	Do.
	Easton, Pa.	Cream white	do	Average.
Wulfenite	Yuma County, Calif.	None	Zero	Do.
	Organ Mountains, N. Mex.	do	do	Do.
Wurtzite	Butte, Mont.	do	do	Do.
Xanthophyllite	Zlatoust, Siberia	do	do	Do.
Yttriofluorite. (See fluorite.)				
Zeolite. (See natrolite, mesolite, thomsonite, laumontite.)				
Zoisite	Mount Rosa, Switzerland	do	do	Do.
Thulite	Pine Nut Mountains, Nev.	Pale brown	Medium	Do.
Saussurite	Voll, Switzerland	None	Zero	Faint.

Mineral	Locality	Infrared luminescence			Emission wavelength
		Strength	Range of excitation	Maximum of excitation	
Valleite. (See anthophyllite.)	Yuma County, Ariz. Tucson, Ariz.	Very weak.	Indeterminable.	Indeterminable.	Medium.
Vanadinite		do.	Red, blue, blue-violet.	Blue-violet.	Long.
Vanuxemite. (See hemimorphite.)	Llallagua, Bolivia. Barnstable, England.	Weak.	Red through blue-violet.	Red through blue-violet.	Short.
Wavellite		do.	do.	Green, blue.	Medium.
Fischerite	Hungary.	do.	do.	Green.	Do.
Willemite	Sussex County, N. J.	do.	Red through blue.	Red through blue.	Do.
Wollastonite	Chelsea, Ontario	do.	Red through blue-violet.	do.	Do.
Wulfenite	Easton, Pa.	do.	Red through blue.	do.	Do.
	Yuma County, Calif.	do.	Red.	Red.	Long.
Wurtzite	Organ Mountains, N. Mex.	do.	do.	do.	Medium.
	Butte, Mont.	do.	Red through blue-violet.	Green.	Long.
Xanthophyllite.	Zlatoust, Siberia	do.	Red, blue, violet.	Violet.	Medium.
Yttriofluorite. (See fluorite.)					
Zeolite. (See natrolite, mesolite, thomsonite, laumontite.)					
Zoisite.	Mount Rosa, Switzerland.	Medium.	Red through blue.	Red, green.	Short.
Thulite.	Pine Nut Mountains, Nev.	Weak.	Red.	Red.	Medium.
Saussurite.	Voll, Switzerland.	Strong.	Red through blue.	do.	Do.

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the 1990s, the number of people in the world who are undernourished has increased from 600 million to 800 million.

There are a number of reasons for this increase. First, the world population has increased by 1.5 billion in the last 20 years. Second, the number of people who are undernourished has increased in almost every country in the world. Third, the number of people who are undernourished has increased in almost every region of the world. Fourth, the number of people who are undernourished has increased in almost every country in the world. Fifth, the number of people who are undernourished has increased in almost every region of the world. Sixth, the number of people who are undernourished has increased in almost every country in the world. Seventh, the number of people who are undernourished has increased in almost every region of the world. Eighth, the number of people who are undernourished has increased in almost every country in the world. Ninth, the number of people who are undernourished has increased in almost every region of the world. Tenth, the number of people who are undernourished has increased in almost every country in the world.

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