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BLACK BODIES IN THE EXTREME INFRA-RED

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ABSTRACT

Absorbing power of various materials of wave-lengths greater than 50μ.—For blackening a receiver of a thermocouple for radiation for obtaining pure rotation band spectra, it is desirable to use a material that is an efficient absorber of the extreme infra-red but a poor absorber of radiation of shorter wave-lengths. The absorbing power of 25 materials were tested for radiation of wave-lengths near 4μ and greater than 50μ. Of all the materials tested, white lead, litharge, red phosphorus, powdered glass, copper sulphide, and celestite were found the best for covering a receiver to absorb the extreme infa-red radiation. The 25 materials were tested by painting them on a receiver of a thermocouple which was exposed to extreme infra-red radiation. The same receiver and thermocouple were used throughout the experiment. A D'Arsonval type galvanometer was improved by using a quartz suspension and replacing each conducting lead with silver leaf or gold plated silver ribbon 1μ thick wound in a spiral.

Glass as a source of extreme infra-red radiation.—Hot glass made a good source of extreme infra-red radiation when used with a cold thin glass shutter.

INTRODUCTION

While working with thermocouples and radiometers in the extreme infra-red, it was found that nothing was known quantitatively of the absorbing qualities of the materials used for blackening the receiver. Since the efficiency of the receiver depends on its absorbing power, it was fundamentally important to know the relative merits of the various materials suitable for blackening a receiver. Twenty-five such materials were selected and comparisons made of their respective absorbing powers for both extreme and near infra-red radiation. It was desired to find a material that was black for infra-red radiation of wave-length greater than 50μ and a poor absorber of shorter radiation and especially adapted for coating a thermocouple or radiometer. Some materials that had no practical usefulness were also tested to see if any were exceptional absorbers of the extreme infra-red.

The experimental difficulties encountered in working with radiation of longer wave-length than 50μ is due mostly to the very small amount of energy available in that region and the interference of the large amount of shorter radiation. Various means are used to filter out the shorter radiation. A black body at 1000°K radiates 57 percent of its energy between 2μ and 5μ[1] and only 0.08 percent of its energy in wave-lengths greater than 50μ. Increasing the temperature to 2000°K increases the energy between 2μ and 5μ 12-fold while radiation of 70μ is only increased $2\frac{1}{2}$ times; the proportion is less favorable at 3000°K.

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[1] L. L. Holladay, J.O.S.A. **17,** 333 (1928).

The small amount of energy available makes it desirable to use a material that is an efficient absorber of long waves; also, it would be desirable if the material were a poor absorber of the near infra-red. The desirability of a material depends on the type of receiving apparatus. For thermocouples, the material should be a good heat conductor, so that it will quickly heat the metal receiver. For radiometers, it is better to use a poor heat conductor so that the back side of the vane will be cool; also, it is better to have a high temperature gradient.[2,3]

A material that absorbs the extreme infra-red well could be used as a source, if the temperature is not too high to alter the physical or chemical state of the material, so that Kirchoff's law would no longer apply. Here, too, it would be an advantage to use a material that is a poor absorber of the short infra-red.

THE EXPERIMENTAL ARRANGEMENT

The apparatus was essentially that used by most investigators of pure rotation band spectra with regard to the method of isolating the long wavelengths. Fig. 1 shows schematically the apparatus. The source of radiation consisted of an electric heater painted with ground glass in tartaric acid and sugar. The temperature was held constant at 1000°K. The radiation was reflected from a stainless steel mirror that had been ground rough with emery. The average depth of the pits was about 8μ and since the reflection was at 45°, the effective depth was about 6μ. A crystalline window 0.83 mm thick was sooted with camphor smoke, so that it was opaque to sunlight. The thermocouple was a balanced type and was shielded from stray radiation and conduction. The wires were 0.033 mm in diameter and had a high ther-

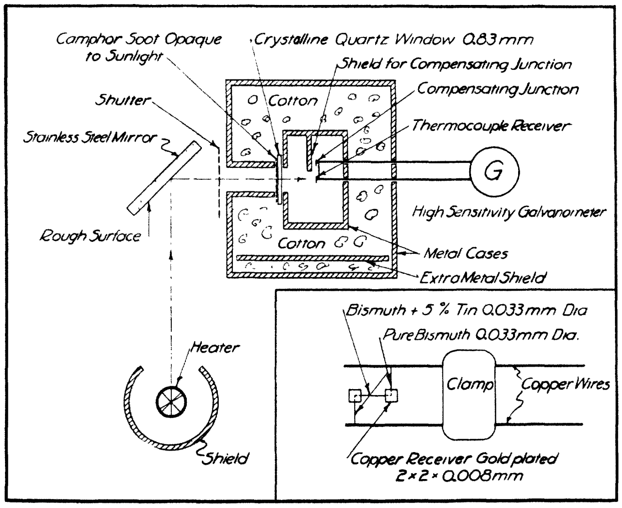

Fig. 1. Apparatus.

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[2] G. Hettner, Zeits. f. Physik **47**, 499 (1928).

[3] Paul S. Epstein, Zeits. f. Physik **54**, 537 (1929).

moelectric power. The receivers were gold plated copper 2 mm by 2mm and 0.008 mm thick. The receivers were waxed to the thermojunctions. Two shutters, one of metal and one of microscope cover glass 0.014 mm thick were used separately and in combination. The galvanometer had a sensitivity of 11 mm microvolt when critically damped. It was found desirable to rebuild the galvanometer in order to get more reliable measurements. The silver ribbon suspension was replaced by a quartz fiber and the conducting leads were each made from a narrow strip of silver leaf. The galvanometer with this arrangement was much improved for there was practically no zero shift even for deflections of two feet at a meter scale distance. Another advantage of this arrangement was that the silver leaf damped out forced vibrations due to earth tremors. A more rugged and simple construction, suggested by Mr. Julius Pearson, consisted of making each conducting lead of a gold plated silver ribbon rolled to 1μ thickness and wound into a flat spiral.

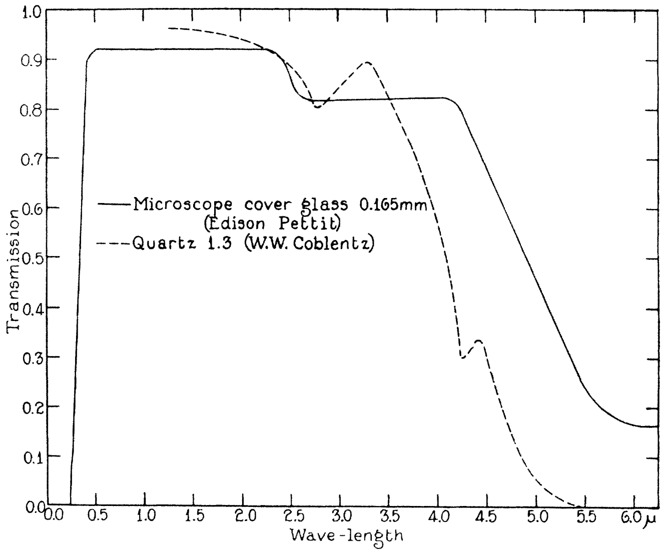

Fig. 2. Transmission of quartz and thin glass, 0–6.2μ.

Fig. 2[4,5] shows the transmission curve for quartz and a microscope cover glass. The quartz becomes opaque at 5μ but transmits wave-lengths greater than 50μ except for a narrow absorption band at 78μ. The microscope cover glass remains opaque to long wave-lengths.

Four groups of readings were taken, using (1) the metal shutter to exclude all radiation, (2) the glass shutter to exclude all of the extreme infra-red but only a small fraction of the near infra-red, (3) the glass shutter always in and moving the metal shutter to find the effect of the near infra-red, and (4) the metal shutter again to see if conditions had remained constant during the

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[4] Edison Pettit, Astrophys. J. **61,** 163 (1926).

[5] W. W. Coblentz, B. S. Bull. **2-3,** 462 (1906).

experiment. Designating by V the energy below 5μ that is received by the thermocouple without any shutter, I the energy above 50μ under the same conditions, and k the fraction of energy below 5μ either reflected or absorbed by the glass shutter, the four groups become:

$$(1),\ V+I;\qquad (2),\ kV+I;\qquad (3),\ (I-k)V;\qquad (4),\ V+I.$$

(2) and (4) are redundant but are useful as a check and for taking averages. Thus: $(2)-(1)=(3)$ and $(2)+(3)=(1)=(4)$.

The value of k can be seen from Fig. 2 to be between 0.15 and 0.20. The value of k was determined experimentally by using an additional window of microscope cover glass 0.008 mm thick, and using the metal shutter to find V and the glass shutter to find kV. The value of k was found to be 0.18. This value depends on the particular apparatus and in a small way on the material used to blacken the receiver.

The table shows the relative blackness or absorbing power of the different materials tested.

TABLE I. *Absorbing power of various materials.*

Substance	Radiation absorbed for $\lambda<5\mu$ V	$\lambda>50\mu$ I	I/V
1. Litharge	10.8	4.3	.40
2. Ground Glass	11.9	4.7	.40
3. Powdered Glass	11.7	5.0	.43
4. White Lead 2 Pb $CO_3 \cdot Pb(OH)_2$	14.9	4.9	.33
5. White Lead in lacquer	14.3	4.4	.31
6. Red Phosphorus	18.3	5.0	.27
7. Red Phosphorus from a match box	17.7	5.1	.29
8. Celestite, powdered $SrSO_4$	14.7	4.6	.31
9. Brucite, powdered $Mg(OH)_2$	11.4	4.2	.37
10. Angelsite, powdered $PbSO_4$	14.2	4.2	.30
11. Copper Sulphide	17.1	5.2	.30
12. Copper Oxide	13.8	4.4	.32
13. Silver Sulphide	12.8	4.4	.34
14. Copper sulphate crystals from solution	15.0	4.1	.27
15. Wellsbach mantle material	8.9	3.1	.35
16. Platinum Black	18.2	4.4	.24
17. Tartaric Acid and Sugar	16.0	3.9	.24
18. Talc $H_2MgSi_4O_{12}$	12.5	3.8	.30
19. Water glass	12.1	3.7	.31
20. Tellurium, powdered	19.2	3.3	.17
21. India Ink	18.8	3.8	.20
22. Lacquer	8.6	3.0	.35
23. Castor Oil	8.8	2.8	.32
24. Glycerine	11.2	3.1	.28
25. Turpentine	8.1	0.2	.02
26. Clean Receiver	2.9	0.2	.07

Some of the materials were selected because they were transparent to near infra-red, some because they had been used by investigators of the extreme infra-red. The powdered materials were painted on the receiver by mixing them with one part turpentine and five parts alcohol. After a material was tested, the receiver was carefully cleaned and painted with another material. Care was taken to replace the thermocouple in the apparatus in the same place each time. The absorbing materials were painted with uniform thickness on the receiver and in each case the thickness of the coat was about 0.01 mm as estimated under a microscope.

Water glass was very unsuitable for a delicate thermocouple for it caused the heavy receiver used here to curl. The glue mixed with the red phosphorus taken from a match box also caused the receiver to curl.

Item 25 in the table shows that turpentine did not absorb the long waves. To determine whether they were reflected or transmitted by the turpentine, a receiver painted with white lead in lacquer was covered with turpentine. The far infra-red was absorbed equally well which showed that turpentine is transparent to long wave-lengths.

The absorbing power of a receiver depends on the thickness of the absorbing material. A copper receiver tarnished with H_2S, so that it appeared quite black was about 50 percent efficient in the near infra-red and only 25 percent efficient in the extreme infra-red, compared with a 0.01 mm coat of copper sulphide painted on the receiver. The physical state of the receiver affects its absorbing power. A receiver, electroplated rapidly with copper, so that the surface was rough, absorbed the far infra-red well; it had a ratio of $I/V=0.28$. A heavy coat of platinum black electroplated on a receiver had the same absorption as if it were painted on the receiver.

The transmission of crystalline quartz, hard rubber, and a cellulose paper used for wrapping candy was also tested to compare their merits as window material. The cellulose paper is very strong and gas tight. The same apparatus was used and the radiation made to shine through the sample being tested. The following table shows the percentage of radiation transmitted by the three samples, used as extra windows:

Material	V	I	I/V
Cellulose paper, 0.033 mm	47%	37%	0.79
Crystalline quartz, 0.83 mm	70	23	0.33
Hard Rubber, 1.2 mm	11	6	0.55
Without an extra window	100	100	0.30

The reflection of the far infra-red from a glass surface was tested by replacing the rough mirror by a piece of plate glass. The ratio of the number of waves reflected from the plate glass to the number reflected from the rough steel mirror was 31 percent.

CONCLUSION

It is to be noticed that the absorptive power of the materials tested was an integrated effect extending over the entire far infra-red.

Litharge, powdered glass, white lead, copper sulphide, celestite, and red phosphorus were the best absorbers of radiation longer than 50μ.

The physical state of the receiver determined its efficiency. A very thin coat of the absorbing material in most cases was an inefficient absorber of the extreme infra-red waves. A very poor absorbing material such as copper or platinum will absorb if the surface is sufficiently rough.

For radiometers, the absorbing material is better when mixed with turpentine and alcohol and painted on the vanes. Very delicate fly-wing radiometers were made in this manner, weighing only 0.04 mg. The vanes were double and a sputtered mica mirror was used.

For thermocouples, absorbing material is better if it is mixed with lacquer. The thermocouples must be in vacuum to be steady; in some cases an increase of 60 times the sensitivity was obtained by evacuation.

The high absorption in glass of the extreme infra-red and its low absorption of the near infra-red suggested its use as a source. Such a source was made by covering with glass two platinum wires that were separated 4 mm. The wires were heated by an electric current and the hot portion of glass between the two wires served as a source of extreme infra-red radiation. This source was tested in a vacuum spectrometer[6] and found to be satsifactory.

A convenient method of filtering out the near infra-red is to grind the windows with emery so that the pits are about 4μ deep. The apparatus can be aligned with visible light by covering the rough surface with turpentine.

Although a tarnished metal surface is not an efficient absorber of the extreme infra-red, it may be desirable to sacrifice efficiency for the extra speed with which the thermocouple will come to thermal equilibrium,—particularly if the readings are recorded photographically. The receiver of a thermocouple can be improved by pressing it against the surface of a file to make the surface rough. A thermocouple with tarnished silver receivers reached equilibrium in one second. White lead is especially desirable for blackening a receiver for it is white to visible light and allows almost perfect alignment of the apparatus.

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[6] Badger and Cartwright, Phys. Rev. **33**, 696 (1929).