therefore, be a limiting value of A applicable to a body which would absorb all the heat that falls upon it and not absorb or transmit any. Such a body would possess perfect emissive power for radiant heat. Hence it appears that good radiation depends rather upon defect of resistance than upon any positive power. A perfect radiator would be a substance whose surface offered no resistance to the passage of radiant heat in either direction; while an imperfect radiator is one whose surface allows a portion to be communicated through it, and reflects another portion regularly or irregularly.

The reflecting and diffusive powers of lamp-black are so insignificant, at temperatures below 100°, that this substance is commonly adopted as the type of a perfect radiator, and the emissive and absorptive powers of other substances are usually expressed by comparison with it.

CHAPTER XIV.

RADIATION (CONTINUED).

197. Thermoscopic Apparatus employed in researches connected with Radiant Heat.—An indispensable requisite for the successful study of radiant heat is an exceedingly delicate thermometer. For this purpose Leslie, about the beginning of the present century, invented the differential thermometer, with which he conducted some very important investigations, the main results of which are still acknowledged to be correct. Modern investigators, as Melloni, Laprovostaye, &c., have exclusively employed Nobili's thermo-multiplier, which is an instrument of much greater delicacy than the differential thermometer.

The thermo-pile, invented by Nobili, and improved by Melloni, consists essentially of a chain (Fig. 119) formed of alternate elements of bismuth and antimony. If the ends of the chain be connected by a wire, and the alternate joints slightly heated, a thermo-electric current will be produced, as will be explained hereafter. The amount of current increases with the number of elements, and with the difference of temperatures of the opposite junctions.

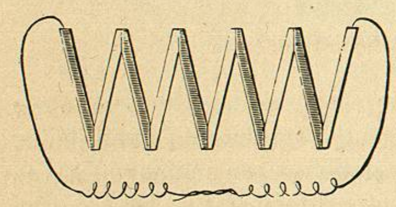

Fig. 119.—Nobili's Thermo-electric Series.

In the pile as improved by Melloni, the elements are arranged side by side so as to form a square bundle (Fig. 120), whose opposite ends consist of the alternate junctions. The whole is contained in a copper case, with covers at the two ends, which can be removed when it is desired to expose the faces of the pile to the action of heat. Two metallic rods connect the terminals of the thermo-electric series with wires leading to a galvanometer,[1] so that the existence of any current will immediately be indicated by the deflection of the needle. The amounts of current which correspond to different deflections are known from a table compiled by a method which we shall explain hereafter. Consequently, when a beam of radiant heat strikes the pile, an electric current is produced, and the amount of this current

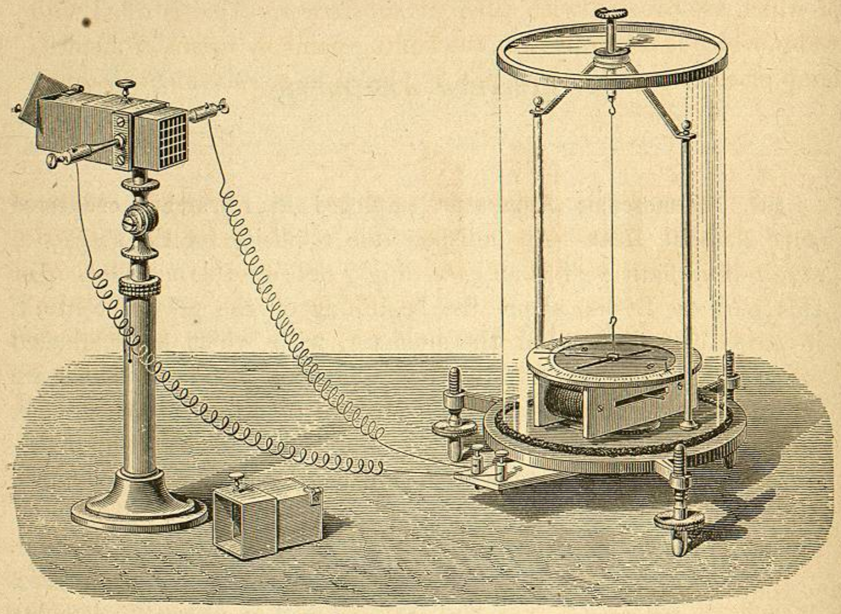

Fig. 120.—Melloni's Thermo-multiplier.

is given by the galvanometer. We shall see hereafter, when we come to treat of thermo-electric currents, that within certain limits, which are never exceeded in investigations upon radiant heat, the current is proportional to the difference of temperature between the two ends of the pile. As soon as all parts of the pile have acquired their permanent temperatures, the quantity of heat received during any interval of time from the source of heat will be equal to that lost to the air and surrounding objects. But this latter is, by Newton's law, proportional to the excess of temperature above the surrounding air, and therefore to the difference of temperature between the two ends of the pile. The current is therefore proportional to the quantity of heat received by the instrument. We have thus in Nobili's pile a thermometer of great delicacy, and admirably adapted

[1] The pile and galvanometer together constitute the thermo-multiplier.

to the study of radiant heat; in fact, the immense progress which has been made in this department of physics is mainly owing to this invention of Nobili.

198. Measurement of Emissive Powers.—The following arrangement was adopted by Melloni for the comparison of emissive powers. A graduated horizontal bar (Fig. 121) carries a cube, the different sides of which are covered with different substances. This is filled with water, which is maintained at the boiling-point by means of a spirit-lamp placed beneath. The pile is placed at a convenient distance,

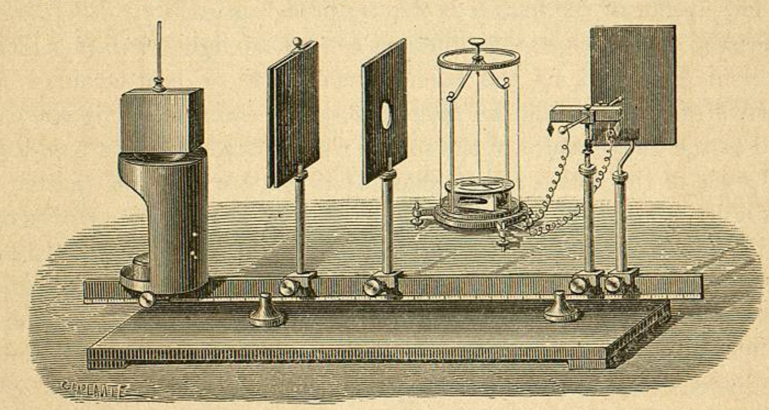

Fig. 121.—Measurement of Emissive Powers.

and the radiation can be intercepted at pleasure by screens arranged for the purpose. The whole forms what is called Melloni's apparatus.

If we now subject the pile to the heat radiated from each of the faces in turn, we shall obtain currents proportional to the emissive powers of the substances with which the different faces are coated.

From a number of experiments of this kind it has been found that lamp-black has the greatest radiating power of all known substances, while the metals are the worst radiators. Some of the most important results are given in the following table, in which the emissive powers of the several substances are compared with that of lamp-black, which is denoted by 100:—

Relative Emissive Powers at 100° C.

Lamp-black,	100	Steel,	17
White-lead,	100	Platinum,	17
Paper,	98	Polished brass,	7
Glass,	90	Copper,	7
Indian ink,	85	Polished gold,	3
Shellac,	72	Polished silver,	3

By modified arrangements of the same apparatus, he measured the absorbing, reflecting, diffusing, and transmitting powers of different substances, and established the fact that all those powers vary according to the source from which the incident radiation is derived.

For example when the source was a hot-water cube, lamp-black and white-lead showed equal absorptions; but when it was the flame of an oil lamp, the absorbing power of white-lead was only 53 per cent of that of lamp-black.

The upshot of the matter is that radiant heat exhibits differences precisely analogous to the different colours of light—a fact which Melloni expressed by the name *thermochrose* or heat-colour. A hot-water cube or other non-luminous source emits only long waves; and as the temperature of the source rises, shorter waves are added, till some of the waves are so short as to come within the limits of visibility, and the body is then said to be *incandescent*. Waves of radiant heat, when short enough to produce the sensation of vision, are called waves of light, and there is no difference between radiant heat and light except a difference of wave-length.

199. Diathermancy. — The fact that radiant heat from non-luminous sources could be transmitted through certain transparent substances was established by Pictet of Geneva; and Prévost confirmed the fact by showing that such transmission could occur even through a sheet of ice. Substances which transmit radiant heat are called *diathermanous*. Diathermancy is merely transparency to rays of long wave-length.

Rock-salt is noted for its diathermancy. Even when dirty-looking, it is much more transparent to dark rays than the clearest glass. Alum, on the other hand, is noted for its opacity to dark rays, and quartz (rock crystal) for its transparency to ultra-violet rays.

Tyndall has shown that a solution of iodine in bisulphide of carbon, though excessively opaque to light, allows heat to pass in large quantity. He raised platinum foil to incandescence by placing it in the focus of the mirror of an electric lamp whose light was stopped by interposing a rock-salt trough containing this solution. To this transformation of dark radiant heat into light he gave the name of *calorescence*.

200. Selective Emission and Absorption.—In order to connect together the various phenomena which may be classed under the general title of selective radiation and absorption, it is necessary to form some such hypothesis as the following. The atoms or molecules of which any particular substance is composed, must be supposed to be capable of vibrating freely in certain periods, which, in the case of gases, are sharply defined, so that a gas is like a musical string, which will vibrate in unison with certain definite notes and with no intermediate ones. The particles of a solid or liquid, on the other hand, are capable of executing vibrations of any period lying between certain limits; so that they may perhaps be compared to the body of a violin, or to the sounding-board of a piano; and these limits (or at all events the upper limit) alter with the temperature, so as to include shorter periods of vibration as the temperature rises.

These vibrations of the particles of a body are capable of being excited by vibrations of like period in the external ether, in which case the body absorbs radiant heat. But they may also be excited by the internal heat of the body; for whenever the molecules experience violent shocks, which excite tremors in them, these are the vibrations which they tend to assume. In this case the particles of the body excite vibrations of like period in the surrounding ether, and the body is said to emit radiant heat.

One consequence of these principles is that a diathermanous body is particularly opaque to its own radiation. Rock-salt transmits 92 per cent of the radiation from most sources of heat; but if the source of heat be another piece of rock-salt, especially if it be a thin plate, the amount transmitted is much less, a considerable proportion being absorbed. The heat emitted and absorbed by rock-salt is of exceedingly low refrangibility.

Glass largely absorbs heat of long period, such as is emitted by bodies whose temperatures are not sufficiently high to render them luminous, but allows rays of shorter period, such as compose the luminous portion of the radiation from a lamp-flame, to pass almost entire. Accordingly glass when heated emits a copious radiation of non-luminous heat, but comparatively little light.

Experiment shows that if various bodies, whether opaque or transparent, colourless or coloured, are heated to incandescence in the interior of a furnace, or of an ordinary coal-fire, they will all, while in the furnace, exhibit the same tint, namely the tint of the glowing coals. In the case of coloured transparent bodies, this implies that the rays which their colour prevents them from transmitting from the coals behind them are radiated by the bodies themselves most copiously; for example, a glass coloured red by oxide of copper permits only red rays to pass through it, absorbing all the rest, but it does not show its colour in the furnace, because its own heat causes it to radiate just those rays which it has the power of absorbing, so that the total radiation which it sends to the eye of a spectator, consisting partly of the radiation due to its own heat, and partly of rays which it transmits from the glowing fuel behind it, is exactly the same in kind and amount as that which comes direct from the other parts of the fire. This explanation is verified by the fact that such glass, if heated to a high temperature in a dark room, glows with a green light.

A plate of tourmaline cut parallel to the axis has the property of breaking up the rays of heat and light which fall upon it into two equal parts, which exhibit opposite properties as regards polarization. One of these portions is very largely absorbed, while the other is transmitted almost entire. When such a plate is heated to incandescence, it is found to radiate just that description of heat and light which it previously absorbed; and if it is heated in a furnace, no traces of polarization can be detected in the light which comes from it, because the transmitted and emitted light exactly complement each other, and thus compose ordinary or unpolarized light.

Spectrum analysis as applied to gases furnishes perhaps still more striking illustrations of the equality of selective radiation and absorption. The radiation from a flame coloured by vapour of sodium—for example, the flame of a spirit-lamp with common salt sprinkled on the wick—consists mainly of vibrations of a definite period, corresponding to a particular shade of yellow. When vapour of sodium is interposed between the eye and a bright light yielding a continuous spectrum, it stops that portion of the light which corresponds to this particular period, and thus produces a dark line in the yellow portion of the spectrum.

An immense number of dark lines exist in the spectrum of the sun's light, and no doubt is now entertained that they indicate the presence, in the outer and less luminous portion of the sun's atmosphere, of gaseous substances which vibrate in periods corresponding to the position of these lines in the spectrum.

201. Our knowledge of solar radiation has been greatly extended in recent years by the researches of Professor Langley of the Smithsonian Institution, conducted by means of an instrument of his own invention called the *bolometer*, which is more sensitive than a

thermopile. The instrument contains an exceedingly fine platinum wire, which is placed successively in different portions of the spectrum; and any change in the temperature of this wire, however slight, is immediately revealed by the deflection of a galvanometer, the wire being, in fact, one of the two arms of a "Wheatstone's Bridge" (§ 209, Part III.).

In order to avoid the absorption of some of the sun's rays which necessarily occurs in transmission through lenses and prisms, he availed himself of the concave "gratings" recently invented by Rowland (§ 271, Part IV.), which produce a spectrum without the aid of a lens.

He has thus been able to trace the ultra-red portion of the solar spectrum much further than it was ever traced before. The wave-length of the extreme violet, in terms of the unit generally employed, being about 3900, and that of the extreme red about 7600, he has traced the ultra-red as far as wave-length 28,000.

By comparing observations made at different heights, some of them being at an elevation of 13,000 feet, on Mount Whitney in Southern California, he has shown that the atmosphere is more transparent to these ultra-red rays than to any others, and that all through the spectrum the absorption is in some inverse ratio to the wave-length. The notion, which has been entertained by many competent authorities, that the atmosphere acts like the glass of a green-house and keeps the earth warm by its opacity to long waves, must, therefore, be discarded, at all events for such climates as those of Pennsylvania and Southern California.