to discover some accurate method of measuring temperatures higher than 600° F.

III.—RADIATION OF HEAT.

Propagation of Heat.

193. HEAT may be transmitted from one body to another through an intervening space. This is shown by the sensation experienced on standing near a fire or heated body.

Heat is sent forth from a heated body in all directions in the same manner that rays of light proceed from a luminous body.

Heat thus propagated is called *radiant heat*, and the lines along which the propagation takes place, are called *rays of heat.*

The property of radiating heat is not confined to incandescent bodies, like a candle, the sun, or burning coals, but it is common to all bodies. The process of mutual radiation is continually taking place between bodies, the tendency of which is to produce uniformity of temperature.

Laws of Radiant Heat.

194. The radiation of heat takes place according to the following laws:

1. *Heat is radiated equally in all directions.*

This law may be verified by placing thermometers at equal distances and in different directions from a heated body.

2. *Rays of heat are straight lines.*

This law may be verified by interposing a screen anywhere in a right line joining the heated body and the thermometer, when the thermometer will cease to rise.

(**193**) How does it appear that heat may be transmitted through space? What is radiant heat? What are rays of heat? Is radiation continually going on? Tendency? (**194**.) What is the first law of radiant heat? *How verified?* What is the second law? *How verified?*

If radiant heat passes from one medium to another, however, the rays of heat are bent from a rectilinear course. This bending is called *refraction*, and is entirely analogous to the refraction of light, which is yet to be explained.

3. *The intensity of radiant heat varies directly as the temperature of the radiating body, and inversely as the square of the distance to which it is transmitted.*

The first part of this law is verified by exposing one of the bulbs of a differential thermometer to a blackened cubical box, filled with hot water, the other bulb being protected by a screen. If the water is in the first instance of a given temperature, and then falls to a half, or a third of that temperature, the differential thermometer will manifest a half, or a third of its original indication, and so on for any temperature.

The second part of the law may also be verified by means of the differential thermometer. In this case the heated body is kept always at the same temperature, and one bulb of the differential thermometer is placed at different distances from it. It will be found that at a double distance the indication is only a fourth of the original indication, at a triple distance only a ninth, and so on.

These laws are rigorously true in a vacuum; in the air they may be approximatively verified, but not absolutely, on account of the action of the atmosphere upon radiant heat, as will be explained hereafter.

Mutual Exchange of Heat between bodies.

195. The process of radiation of heat between bodies is *mutual* and *continuous.* According to the laws given in the preceding article, those bodies which are most heated give off most heat; hence, the hottest bodies of a group give off more heat than they receive, and the coldest ones receive more than they give off. The consequence is that there is a continual tendency towards equalization of tem-

What is the third law? *How is the first part of the law verified? The second part? Are these laws rigorously true in the air?* (**195**.) Explain the action of radiation to produce uniformity of temperature.

perature. If all the bodies are of the same temperature, each will give off as much as it receives, and no further change of temperature can occur. The process of radiation, however, goes on as before.

All the bodies in a room, for example, tend to come to a uniform temperature. We say, tend to come to a uniform temperature, because this condition is never fully realized. Bodies nearest the walls are continually exchanging heat with the walls, and as these are in communication, either with the outer air, or with other rooms, their temperature will be influenced thereby, and will in turn exert an influence upon the remaining bodies in the room.

V.—REFLECTION, ABSORPTION, EMISSION, AND CONDUCTIBILITY.

Reflection of Heat.

196. When a ray of heat falls upon the surface of a body, it is divided into two parts, one of which enters the body and is absorbed, whilst the other is deflected or bent from its course. This bending is called *reflection.*

The point at which the bending takes place, is called *the point of incidence.* The ray before incidence is called *the incident ray;* after incidence it is called *the reflected ray.* If a perpendicular be drawn to the surface at the point of incidence, it is called a *normal* to the surface at that point. The plane of the incident ray, and the normal at the point of incidence, is called the *plane of incidence.* The plane of the normal and the reflected ray is called the *plane of reflection.* The angles which the incident and reflected rays make with the normal, are called, respectively, *angles of incidence and reflection.*

Illustrate by the example of articles in a room? (**196**) What is reflection of heat? What is the point of incidence? The incident ray? The reflected ray? The plane of incidence? The plane of reflection? The angles of incidence and reflection?

Laws which govern the Reflection of Heat.

197. The following laws, indicated by theory, have been confirmed by experiment:

1. *The planes of incidence and reflection coincide.*
2. *The angles of incidence and reflection are equal.*

The apparatus, employed in establishing these laws, is shown in Fig. 137. *A* is a tin box with its faces blackened, in which hot water is placed. *B* is a reflecting surface, and *D* is a differential thermometer. *BC* is a normal to the reflecting surface.

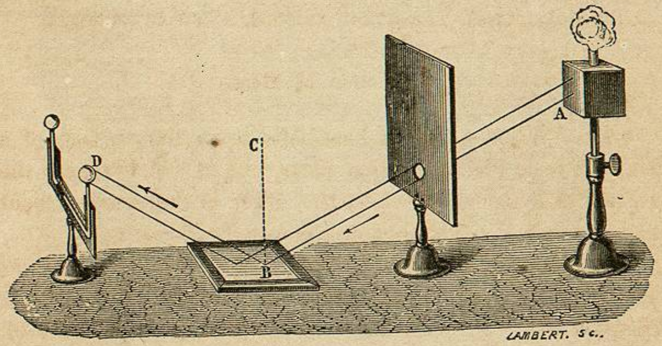

Fig. 137.

The surface, *A*, radiates heat in all directions, but only a single ray is permitted to fall upon the reflector, *B*, the remainder being intercepted by a screen, having a small hole in it. By suitably arranging the thermometer, and other parts of the apparatus, it is shown, whatever may be the value of the angle of incidence, that the planes, *ABC* and *CBD*, coincide with each other, and that the angles, *ABC* and *CBD*, are equal to each other.

(**197.**) What is the first law of reflection? The second law? *Explain the apparatus for verifying these laws. Explain the mode of verification.*

Reflection of Heat from Concave Mirrors.

198. A Concave Mirror is a reflecting surface, curved towards the source of heat. For experimental purposes they are generally parabolical in shape, the axis being a normal to the surface at its middle point.

It is a property of such mirrors that all rays which before incidence are parallel to the axis, are after reflection converged to a single point, which point is the *focus* of the mirror. Conversely, if the rays radiate from the focus they will be reflected in lines parallel to the axis.

A and *B*, Fig. 138, represent two parabolic reflectors, having their axes coincident, and their surface turned to each other. In the focus, *n*, of the mirror, *A*, is placed a ball

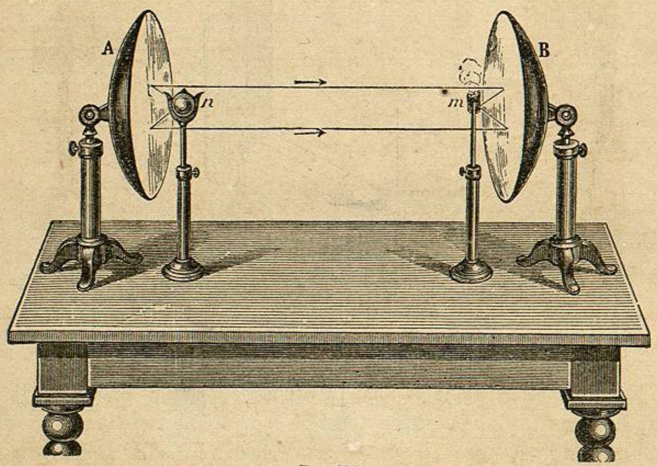

Fig. 138.

of hot iron, and in the focus, *m*, of the mirror, *B*, is placed an inflammable substance, as a piece of phosphorus. The

(198.) What is a Concave Mirror? What is their shape for experiment? How are rays parallel to the axis reflected? What is the focus?

heat radiating from the ball, is reflected from *A*, parallel to the common axis of the mirror, and falling upon *B*, is again reflected to the focus *m*; the heat, concentrated at *m*, is sufficient to inflame the phosphorus, even when the mirrors are several yards distant from each other. If the mirror, *A*, alone is used, the phosphorus is not inflamed.

Fig. 139.

The property of parabolic mirrors, above explained, enables us to concentrate the heat of the sun's rays. In this case the reflector is called a *burning mirror*. Fig. 139 shows the manner of using a burning mirror. It is placed so that its axis is parallel to the rays of the sun, which, on falling upon it, are reflected to the focus, where they produce heat enough to set inflammable substances on fire.

It is said that Archimedes was enabled by means of mirrors to

How are rays from the focus reflected? Explain the experiment. *What is a burning mirror? Explain its use.*

set fire to the Roman ships in the harbor of the City of Syracuse. Buffon showed the possibility of such an operation, by setting fire to a tarred plank, by means of burning mirrors, at a distance of more than 220 feet.

Reflecting Power of different substances.

199. It has been stated that a ray of heat which falls upon a body is divided into two parts, one being *absorbed* and the other *reflected.* The relative proportions between these two parts varies with the nature of the substance and the character of the reflecting surface.

Those bodies which reflect a large portion of the incident heat, are called *good reflectors;* those which reflect but little of the incident heat, are called *bad reflectors.* Good reflectors are *bad absorbers;* and bad reflectors are *good absorbers.*

Fig. 140 shows the method of determining the relative

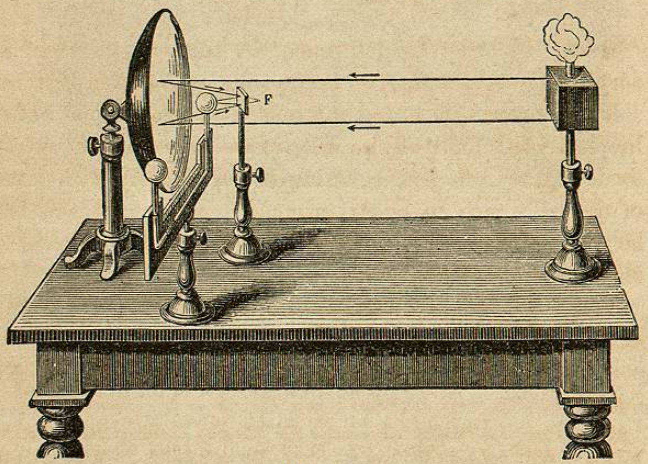

Fig. 140.

(**199.**) Into how many parts is an incident ray divided? What is a good reflector? A bad reflector? A good absorber? A bad absorber?

reflecting powers of different bodies, adopted by Leslie. He placed a cubical tin box filled with water at the boiling point, in front of a parabolic reflector. The rays of heat, falling upon the reflector, are reflected and tend to come to a focus at F, but by interposing a square plate of some substance between the mirror and its focus, the rays are again reflected, and come to a focus as far in front of the plate, as F is behind it. The heat thus reflected is received upon one bulb of a differential thermometer, by means of which it is measured. By interposing plates of different substances in succession, their relative reflecting powers are determined.

In this way Leslie showed, that polished brass possessed the highest reflecting power; silver only reflects nine tenths, tin only eight tenths, and glass only one tenth as much as brass. Plates blackened by smoke do not reflect heat at all.

Power of Absorption.

200. In order to determine the relative powers of absorption, Leslie employed the apparatus shown in Fig. 141.

The source of heat and the reflector remaining as before, he placed the bulb of the differential thermometer in the focus of the reflector, covering it successively with layers of the substance to be experimented upon. In this way he showed, that those substances which reflect most heat absorb least, and the reverse.

When the bulb was blackened by smoke, the thermometer indicated the greatest change of temperature, and when covered with leaves of brass, it indicated the least change.

Explain Leslie's method of determining the reflecting power of different bodies. What did Leslie find to be the best reflector? The next in order? What of blackened plates? (**200.**) Explain Leslie's method of determining the absorbing power of bodies. What was the result of his experiments?

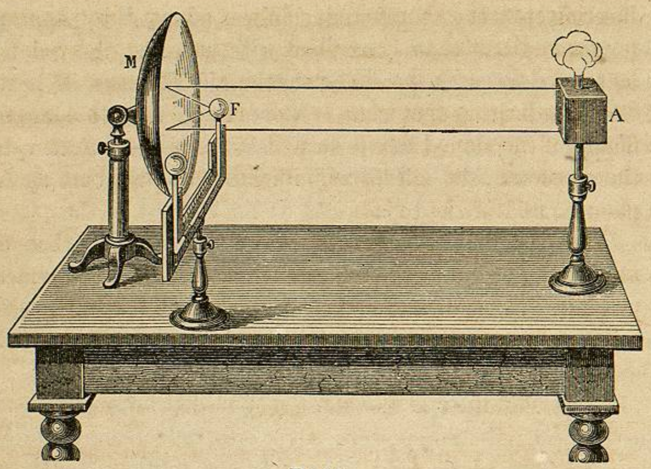

Fig. 141.

Emission Power.

201. The EMISSION POWER of a body is its capacity to *emit*, or *radiate* the heat which it contains.

In determining the emission power, LESLIE employed the apparatus shown in Fig. 141. In this case, instead of covering the bulb of the thermometer with layers of the substances to be experimented upon, he covered the different faces of the cubic box with layers of the different substances.

For example, let one face be made of tin, let a second be blackened by smoke or lamp-black, let a third be covered by a layer of paper, and a fourth by a plate of glass. On turning these different faces towards the reflector, the thermometer indicates different degrees of temperature. If the blackened face be turned towards the reflector, the thermometer rises, showing that this face is a good radiator; if the paper-covered face be next turned towards

(**201.**) What is the Emission Power of a body? Explain LESLIE'S method of determining it. Give an example of his process.

the reflector, the thermometer falls, showing that paper is a poorer radiator than lamp-black; if the glass covered face be turned towards the reflector, the thermometer falls still lower, indicating that glass is a poorer radiator than paper; finally, if the tinned face is turned towards the reflector, the thermometer falls still lower, indicating the fact that tin is a poorer radiator than glass.

LESLIE found by this course of proceeding, that the radiating powers of bodies are the same as their absorbing powers; that is, a good radiator is also a good absorber, but a bad reflector, and the reverse.

Modifications of the Reflecting Powers of Bodies.

202. The principal causes that modify the reflecting and absorbing powers of bodies, are: *polish*, *density*, *direction of the incident rays*, *nature of the source of heat*, and *color*.

Other things being equal, *polished bodies are better reflectors and worse absorbers than unpolished ones.*

Other things being equal, *dense bodies are better reflectors and worse absorbers than rare ones.*

Other things being equal, *the nearer the incident ray approaches the normal, the less will be the portion reflected and the greater the portion absorbed.*

The nature of the source of heat sometimes modifies the reflecting and absorbing powers. Thus, if a body is painted with white lead, it absorbs more heat from a cubical box of boiling water, than though the same heat were emitted by a lamp. But if a body is painted with lamp-black, the amount absorbed is the same, whatever may be its source.

What relation did he find between the radiating and absorbing powers of bodies? (**202.**) What causes modify the reflecting and absorbing powers of bodies? Effect of polish? Of density? Of direction of rays? Of the source of heat?

Other things being equal, *light-colored bodies absorb less and reflect more heat than dark-colored ones.* White bodies are the best reflectors, black ones the worst. White bodies are the worst absorbers, and black ones the best.

Applications of the preceding principles.

203. Articles of clothing are intended to preserve uniformity of temperature in the human body by excluding the too violent heats of summer, and by preventing too rapid radiation of animal heat in winter.

Loose substances, like woollens and furs, are bad radiators, and therefore are suitable for winter clothing. Compact substances, like linens and cottons, are good reflectors, and therefore are suitable for summer clothing. As far as color is concerned, white is best adapted to both seasons, because white bodies are at once better reflectors and worse radiators, than those of dark colors.

The animals of the polar regions are generally of light colors, often becoming completely white in winter. This wise provision of Nature is calculated to adapt them to sustain more readily the severe cold of those inhospitable regions.

Oils and fats are good reflectors and bad radiators. Hence we find the Laplanders and Esquimaux rubbing their bodies with oils to prevent the too rapid radiation of animal heat, whilst the negroes of the tropical regions do the same thing to prevent the absorption of heat from without.

Snow is a good reflector and a bad absorber and radiator. Hence it is that a layer of snow in winter acts to protect the plants which it covers. Snow and ice, when exposed to the rays of the sun, melt but slowly, but if a branch of a tree or stone projects through the snow, it causes the latter to melt in its neighborhood, first by absorbing the heat of the sun, and then radiating it to the surrounding particles of ice or snow.

Of color? (**203.**) *What is the object of clothing? Why are furs and woollens suitable to winter? Linens and cottons to summer? What color is best adapted to all seasons? Color of animals in Arctic regions? Effect of oils and fats on radiation and absorption? Examples. Effect of snow? Why do snow and ice melt slowly?*

If a stone is thrown upon a field of ice, it soon causes the ice around it to melt, forming a hole into which it sinks. A dark cloth spread upon snow acts in the same manner, and soon sinks under the influence of the sun's rays.

Water is soonest heated in a vessel whose surface is black and unpolished, because the vessel in this state is best adapted to absorb the heat which is applied to it, but on removing it from the fire, the water cools rapidly. To retain heat in liquids, they should be confined in dense and polished vessels, as these are poor radiators. Hence, for boiling and cooking, rough and black vessels should be employed, but to keep the articles warm, dense and polished vessels should be used. It is for this reason that a silver teapot is better than an earthen one. But as silver is a good conductor of heat, the handle should be *insulated* by interposing between it and the vessel some non-conducting substance, as ivory or bone.

Stoves, being intended to radiate heat, should be rough and black, but fire-places, being intended to reflect heat into the room, should be lined with white, dense, and polished substances, like glazed earthenware, or glazed fire-bricks.

Conductibility of Solid Bodies.

204. Conductibility is that property of bodies by virtue of which they transmit heat. Those bodies that transmit heat readily, are called *good conductors*; those that do not transmit it readily, are called *bad conductors.*

Ingenhousz showed that solid bodies possess different degrees of conductibility, by means of an apparatus shown in Fig. 142. It consists of an oblong vessel to contain water, from one side of which projects a system of short tubes for receiving rods of different kinds of solids, such as metals, marble, wood, glass, and the like.

Ingenhousz coated the different rods with a soft wax that

Explain the effect of a stone thrown upon ice? Of a dark cloth upon snow? Why is water soonest heated in black and unpolished vessels? In what vessels is it best kept hot? Of what material should stoves be constructed? Fire-places? Why? (**204.**) What is Conductibility? Good conductors? Bad conductors? Explain Ingenhousz' apparatus?

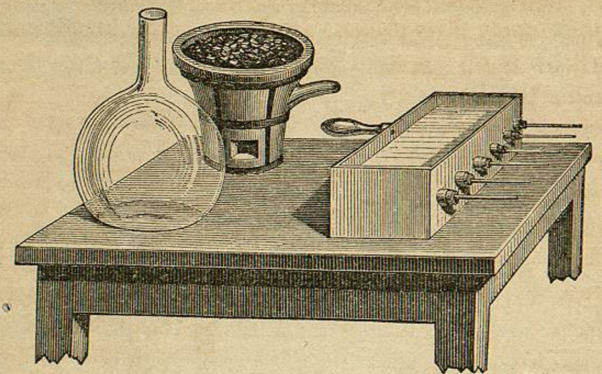

Fig. 142.

would melt at about 140° F., and then filled the vessel with boiling water. Upon some of the rods the wax melted rapidly, upon some more slowly, and upon others not at all. This showed that the rods varied in their conductibility.

It has been shown that metals are the best conductors, after which comes marble, then porcelain, bricks, wood, glass, resin, &c.

Conductibility of Liquids. — Convection.

205. Liquids are bad conductors of heat, except mercury, which is a metal. They are such bad conductors that RUMFORD asserted that water was not a conductor at all. More careful experiments have shown that all liquids are conductors, but all are extremely bad ones.

Liquids are heated by a process of circulation amongst their particles, called *convection*, the heat being applied from below, as shown in Fig. 143. When the particles at the bottom become heated, they expand, and as they are then lighter than the cooler particles above them, they rise to the

Explain his method of using it? *What are the best conductors? What bodies come next in order?* (**205.**) Are liquids good or bad conductors? How are liquids heated? Explain the illustration.

top of the vessel to give place to the heavier and cooler ones that supply their places. In this way a double current of particles is set up, as shown in the figure by the arrows, the hot ones rising and the cool ones descending. This process of circulation goes on till a uniform temperature is imparted to all of the liquid.

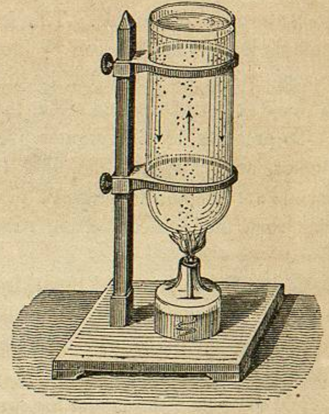

Fig. 143.

The circulation of particles may be shown by putting into the vessel fine particles of a substance of nearly the same density as the liquid; as, for example, oak sawdust. These particles will partake of the motion of the fluid, rising up in the centre, and descending along the walls of the vessel as shown in the figure

Conductibility of Gases.

206. Gases are bad conductors of heat, but on account of the extreme mobility of their particles, it is difficult to establish the fact by direct observation.

Gases are heated by convection, in the same manner as liquids.

Applications of the preceding principles.

207. If the hand be placed upon different articles in a cold room, they convey different sensations. Metals, stones, bricks, and the like, feel cold, whilst carpets, curtains, and the like, feel warm.

How may the circulation of particles be demonstrated? (**206.**) Are gases good or bad conductors? How are they heated? (**207.**) *Explain the different sensations experienced on touching bodies in a room.*