two gases, have been liquefied. Liquid air boils at $-337°$ F. *in a vacuum.* Nitrogen has been obtained in "snow-like crystals of remarkable size," and by reducing the pressure on these a temperature of $-373°$ F. was attained,—the lowest recorded up to the present date (1887).

7. Spheroidal State.—If a few drops of water be put in a hot, bright spoon, they will gather in a globule, which will dart to and fro over the surface. It rests on a cushion of steam, while the currents of air drive it about. If the spoon cool, the water will lose its spheroidal form, and coming into contact with the metal, burst into steam with a slight explosion.*

8. Specific Heat.—More energy is required to raise the temperature of a pound of water through one degree than for any other substance except the gas hydrogen. The fraction of a heat unit required to produce an equal change of temperature in any other substance is called its *specific heat;* thus for mercury it is about $\frac{1}{30}$; for iron, $\frac{1}{9}$; for air, nearly $\frac{1}{4}$; for hydrogen, $3\frac{4}{10}$. On this account the ocean changes its temperature far less quickly than the land, and sea-side cities are subject to less extremes of temperature than those on the middle of a continent. On the elevated plateau region around the Great Salt Lake the temperature during the year varies from 115° F. to $-30°$ F.

* Drops of water spilled on a hot stove illustrate the principle.—By moistening the finger, we can touch a hot flat-iron with impunity. The water assumes this state, and thus protects the flesh from injury.—Furnace-men can dip their moistened hands into molten iron.

III. COMMUNICATION OF HEAT.

Heat tends to become diffused equally among neighboring bodies.* There are three modes of distribution.

1. Conduction *is the process of heating by the passage of heat from molecule to molecule.—Example:* Hold one end of a poker in the fire, and the other end soon becomes hot enough to burn the hand. Of the ordinary metals, silver and copper are the best conductors.† Wood is a poor conductor, especially "across the grain."

Gases are the poorest conductors; hence porous bodies, as wool, fur, snow, charcoal, etc., which contain large quantities of air, are excellent non-conductors. Refrigerators and ice-houses have double walls, filled between with charcoal, sawdust, or other non-conducting substances. Air is so poor a conductor that persons have gone into ovens that were hot enough to cook meat, which they carried in and laid on the metal shelves; yet, so long as they did not themselves touch any good conductor, they experienced little inconvenience.

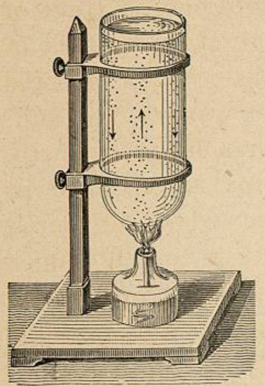
Liquids are also poor conductors.—*Example:*

* If we touch an object colder than we are, it abstracts heat from us, and we say "it feels cold"; if a warmer body, it imparts heat to us, and we say "it feels warm." Adjacent objects have, however, the same temperature, though flannel sheets feel warm, and linen cold. These effects depend upon the relative conducting power of different substances. Iron feels colder than feathers because it robs us faster of our heat.

† Place a silver, a German-silver, and an iron spoon in a dish of hot water. Notice how much sooner the handle of the silver spoon is heated than the others.

Hold the upper end of a test-tube of water in the flame of a lamp. The water nearest the blaze will boil without the heat being felt by the hand.

Fig. 184.



Heating by Convection.

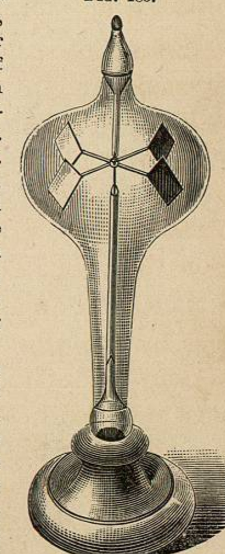
2. Convection *is the process of heating by circulation.* (1.) Convection of Liquids.—Place a little sawdust in a flask of water, and apply heat. We shall soon find that an ascending and a descending current are established. The water near the lamp becoming heated, expands and rises. The cold water above sinks to take its place.

(2.) Of Gases.—By testing with a lighted candle, we shall find at the bottom of a door opening into cold air, a current setting inward, and at the top, one setting outward. The cold air in a room flows to the stove along the floor, is heated, and then rises to the ceiling. Heating by hot-air furnaces depends upon the principle that warm air rises.

3. Radiation *is the transmission of rays in straight lines* by the vibration of the ether. The heat from the sun comes to the earth in this manner. A hot stove radiates heat. Rays of heat do not always elevate the temperature of the medium through which they pass. When the motion of the ether-waves is stopped, the effect is felt.* Space between the earth

and the sun is not warmed by the sunbeam. Meat can be cooked by radiation, while the air around is at the freezing-point. A rough, unpolished surface is a better radiator than a smooth, bright one. Extent of surface increases radiation. Dry air permits most of the solar energy to pass it readily. Vapor absorbs much of it, particularly the shorter waves. The sunbeam becomes thus filtered before reaching the earth, and more than a third of its energy is expended in warming the moist air. Much of what the earth absorbs is radiated forth again, but in much longer waves. To these water vapor is nearly opaque, as are also plates of glass.* These are therefore used

Fig. 185.



The Radiometer.

* The Radiometer is an instrument that, for a time, was supposed to exhibit the actual mechanical force of the sunbeam. It consists of a tiny vane delicately pivoted in a glass globe from which the air is exhausted as fully as possible, when the globe is hermetically sealed. The four arms of the vane carry each a thin light disk of mica or aluminium, covered with lamp-black on one side and uncovered on the other. When daylight falls upon it the little vane revolves rapidly. The motion ceases as soon as the light is cut off. When different gases are admitted into the globe, the rate of rotation varies. It is now believed that the unequal heating of the black and white surfaces of the disks causes unequal reaction of the molecules of air left in the vacuum. Lamp-black being the best absorber and radiator, receives the more forcible bombardment of flying air molecules.

* In the course of Prof. Langley's experiments upon Mount Whitney, water was boiled by exposing it in a copper vessel covered by a pane of window-glass, to the direct rays of the sun. This shows that many of the heat-rays of the sunbeam are stricken down by the air before reaching low levels, but may be utilized at high elevations. So, were the atmosphere removed, the earth would receive far more heat and yet be much colder than now, because there would be no beds of water

for the roofs of greenhouses to keep the plants warm inside. At lofty elevations, like the great plateaus of Central Asia, the dry air allows the heat received by the soil during the day to escape so rapidly that a freezing temperature is felt before the night is ended; and this in turn is followed by torrid heat in the early afternoon.

4. Absorption and Reflection.—A good absorber is also a good radiator, but a good reflector can be neither. Snow is a good reflector, but a poor absorber or radiator. Light colors often absorb solar heat less and reflect more than dark colors.* White is generally considered the best reflector, and black the best absorber and radiator. But the nature of the material is of more importance than its tint. If on a bright summer day three thermometers are exposed to the sun, one held up in mid-air, another resting on a bed of black silk, and the third on a bed of white sand, it will be found in a short time that the temperatures indicated will be very different. The thermometer on the sand will have its bulb more warmed than that on the bed of black silk; and both of these will be warmer than the one in mid-air.

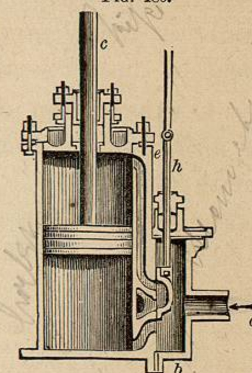
vapor to check the radiation back into space. See "American Journal of Science," March, 1883.

* Experiments show that with artificial heat the molecular condition of the surface varies radiation as well as reflection. In fact, white lead is as good a radiator as lamp-black.—On one side of a sheet of paper paste letters of gold-leaf. Spread over the opposite side a thin coating of scarlet iodide of mercury—a salt which turns yellow on the application of heat. Turn the scarlet side down. Hold over the paper a red-hot iron. The gold-leaf will reflect the heat, but the paper spaces between the letters will absorb it, and on turning the paper over, the gilt letters will be found traced in scarlet on a yellow background.

IV. THE STEAM-ENGINE.

WHEN steam rises from water at a temperature of 212°, it has an elastic force of nearly 15 lbs. per square inch. If the steam be confined and the temperature raised, the elastic force will be rapidly increased.

Fig. 186.



Steam-chest and Cylinder of an Engine.

1. The Steam-engine is a machine for using the elastic force of steam as a motive power. There are two classes, *high-pressure* and *low-pressure*. In the former, the steam, after it has done its work, is forced out into the air; in the latter, it is condensed in a separate chamber by a spray of cold water. As the steam is condensed in the low-pressure engine, a vacuum is formed behind the piston; while the piston of the high-pressure engine acts against the pressure of the air. The elastic force of the steam must be 15 lbs. per square inch greater in the latter case. The figure represents the piston and connecting pipes of an engine. The steam from the boiler passes through the pipe, *a*, into the steam-chest, *b*, as indicated by the arrow. The sliding-valve worked by the rod *h* lets the steam into the cylinder, alternately above and below the piston, which is thus made to play up and down by the expansive force. This valve is so arranged that at the moment fresh