molecules.* (3.) Chemical action is seen in fire. The oxygen of the air has an affinity for the carbon and hydrogen of the fuel. They combine, and chemical energy is transformed into that of sensible heat.

5. Mechanical Equivalent of Heat (*Joule's Law*).—In these various changes of mechanical motion into motion of molecules no energy is destroyed, though some of it may be so transformed as to become incapable of being made to do *useful* work. If the energy transformed by the fall of a blacksmith's hammer on his anvil could be gathered up, it would be sufficient to lift the hammer to the point from which it fell. *A pound-weight falling vertically 772 feet, will generate enough heat to raise the temperature of 1 pound of water through 1° F.;* conversely, this amount of heat is the equivalent of the energy required to lift 1 pound mechanically to a height of 772 feet. This important truth was first demonstrated by Mr. Joule, of Manchester, England, and we express it by saying 772 foot-pounds is the mechanical equivalent of heat. Expressed in metric measures, it is 424 kilogram-meters for 1° C.

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* A horse hits his shoes against a stone and "strikes fire"; little particles of the metal being torn off are heated by the shock, and some of the energy is manifested also as light.—A train of cars is stopped by the pressure of the brakes. In a dark night, we see the sparks flying from the wheels, the motion of the train being converted into heat.—A blacksmith pounds a piece of iron until it glows. His strokes set the particles of metal vibrating rapidly enough to send ether-waves of such swiftness as to affect the eye of the observer.—As a cannon-shot strikes an iron target, a shower of sparks is scattered around.—Were the earth instantly stopped, enough heat would be produced to "raise a lead ball the size of our globe to 384,000° C." If it were to fall to the sun its impact would produce a thousand times more heat than its burning.

[illegible]

II. PHYSICAL EFFECTS OF HEAT.

1. Expansion.—If the molecules of a body have an increase of energy imparted to them they swing, like pendulums, through wider arcs. Each tends to push against its neighbor, and the mass as a whole grows larger. Hence the general law, "Heat expands and cold contracts," cold being merely a relative term implying the withdrawal of energy. The ratio of the increase of volume to the original volume for a change of 1° in temperature is called the *Co-efficient of Expansion.* Generally this is greatest for gases, less for liquids, and least for solids, each particular substance having its own co-efficient. The force of expansion is for many substances irresistible. A rise in temperature of 80° F. will lengthen a bar of wrought-iron, 10 feet long, about $\frac{1}{17}$ of an inch; and if its cross-section is one square inch it will push in expanding with a force of about 25 tons. When the metal cools it will contract with the same force.*

A familiar application of expansion is in the pen-

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* A carriage-tire is put on when hot, in order that, when cooled, it may bind the wheel together.—Rivets used in fastening the plates of steam-boilers are inserted red-hot.—"The ponderous iron tubes of the Britannia Bridge writhe and twist, like a huge serpent, under the varying influence of the solar heat. A span of the tube is depressed only a quarter of an inch by the heaviest train of cars, while the sun lifts it 2½ inches." The same may be noticed on the great Brooklyn Bridge, more than a mile long, where an allowance of nearly a yard has to be made for expansion with the change of seasons.—The Bunker-hill monument nods as it follows the sun in its daily course.—Tumblers of thick glass break on the sudden application of heat, because the surface dilates before the heat has time to be conducted to the interior.

dulum of a clock, which lengthens in summer and shortens in winter. A clock, therefore, tends to lose time in summer and gain in winter. To regulate it we raise or lower the pendulum bob.

Fig. 180.

Gridiron Pendulum.

The *gridiron pendulum* consists of brass and steel rods, so connected that the brass, *h*, *k*, will lengthen upward, and the steel, *a*, *b*, *c*, *d*, downward, and thus the center of oscillation remain unchanged. The *mercurial pendulum* contains a cup of mercury which expands upward, while the pendulum-rod expands downward.

2. Temperature.—When one body is in a condition to communicate heat to another, the first is said to have a higher *temperature* than the second, or to be warmer. We measure temperature usually by noting its effect in producing expansion. Within narrow limits we may form a rough estimate of it by the sensation of touch, but this is very unreliable.

The thermometer is an instrument for measuring temperature, usually by the expansion of mercury.*

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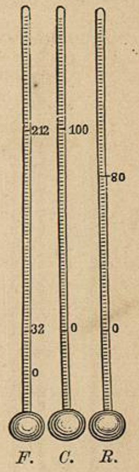
* Take a glass tube terminating in a bulb, and heat the bulb to expel the air. Then plunge the stem in colored water. As the bulb cools, the water will rise and partly fill it. Heat the bulb again until the steam pours out of the stem. On inserting it a second time, the water will fill the bulb. In the manufacture of thermometers, it is customary to have a cup blown at the upper end of the stem. This is filled with mercury, and

To graduate it, according to Fahrenheit's scale (*F.*), each thermometer is put in melting ice, and the point to which the mercury sinks is marked 32°, *Freezing-point.** It is then placed in a steam-bath, and the point to which the mercury rises (when the barometric column stands at 30 inches) is marked 212°, *Boiling-point.* The space between these two points is divided into 180 equal parts. In the Centigrade scale (*C.*) the freezing-point is 0, and the boiling-point 100°. In Reaumur's scale (*R.*), the boiling-point is 80°.† The thermometer does not measure the quantity of heat, but only its intensity.

Fig. 181.



Thermometers.

3. The Heat Unit.—For measuring quantity of heat, the unit commonly employed in England and America is that quantity which is required to raise the temperature of one pound (avoirdupois) of water through one degree (Fahrenheit) above the freezing-point.

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the air, when expanded, bubbles out through it, while the metal trickles down as the bulb cools. The mercury is then highly heated, when the tube is melted off and sealed at the end of the column of mercury. The metal contracts on cooling, and leaves a vacuum above.

* The inventor placed zero 32° below the temperature of freezing water, because he thought that to be absolute cold—a point now estimated to be about 492° below the freezing-point on his scale.

† The following formulæ will be of use in comparing the readings of the different scales:

$$R. = \tfrac{4}{5}\ C. = \tfrac{4}{9}\ (F. - 32^\circ). \quad \ldots \ldots \quad (1.)$$

$$C. = \tfrac{5}{4}\ R. = \tfrac{5}{9}\ (F. - 32^\circ) \quad \ldots \ldots \quad (2.)$$

$$F. = \tfrac{9}{5}\ C. + 32^\circ = \tfrac{9}{4}\ R. + 32^\circ \quad \ldots \ldots \quad (3.)$$

$$1^\circ\ C. = 1.8^\circ\ F. \quad \ldots \ldots \quad (4.)$$

4. Liquefaction or Fusion.—When heat is communicated to a solid body a point is finally reached when the vibratory swing of its molecules is so great that they are driven apart, each toward the limit of the sphere of attraction of its neighbor, so that all rigidity is lost.* The molecules then move freely among themselves. The energy that is applied raises the temperature of the body up to a fixed point called its melting or fusing point, when liquefaction begins. Additional energy then does the work of driving the molecules apart without further rise of temperature, until fusion is complete; after which the liquid rises still further in temperature. Energy that does thus the work of changing the state of a body without at the same time changing its temperature is often called *latent heat.*† If a pound of ice at 32° F. be heated, it requires 142 heat units to melt it, and 180 more to raise its temperature then up to the boiling-point.

Freezing.—The converse of fusion is freezing. Ice melts at 32° F., and in doing so it absorbs energy. Water freezes at 32° F., and in doing so it gives out the energy which had been keeping its molecules apart. Thawing is thus a cooling process and freezing is a warming process. Freezing mixtures depend on this principle. In freezing ice-cream, salt and pounded ice are put around the

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* This is true only of bodies which are not broken into their chemical constituents before the melting-point is reached. A large variety of substances, such as wood, bone, flesh, etc., become chemically changed instead of melting.

† The term *latent heat* is gradually going out of use.

vessel that contains the cream. The strong attraction between salt and water causes the ice to melt rapidly, and the solid salt becomes liquid by solution. This rapid thawing involves much absorption of energy, which comes from the nearest objects whose temperature is higher than that of the solution. The cream thus loses energy, its temperature becoming reduced down to the freezing-point.*

5. Vaporization.—When heat is applied to a liquid the temperature rises until the boiling-point is reached, when it stops and the liquid is changed to vapor at that constant temperature. The vapor is nearly free from solids dissolved in the liquid.—*Example:* Pure or distilled water is obtained by heating water in a boiler, *A*, whence the steam passes through the pipe, *C*, and the *worm* within the condenser, *S*, where it is condensed and drops into the vessel, *D*. The pipe is coiled in a spiral form within the condenser, and is hence termed the worm. The condenser is kept full of cold water from the tub at the left. By carefully regulating the temperature, one liquid may be separated from another by "fractional" distillation, advantage being taken of the fact that each liquid has its own boil-

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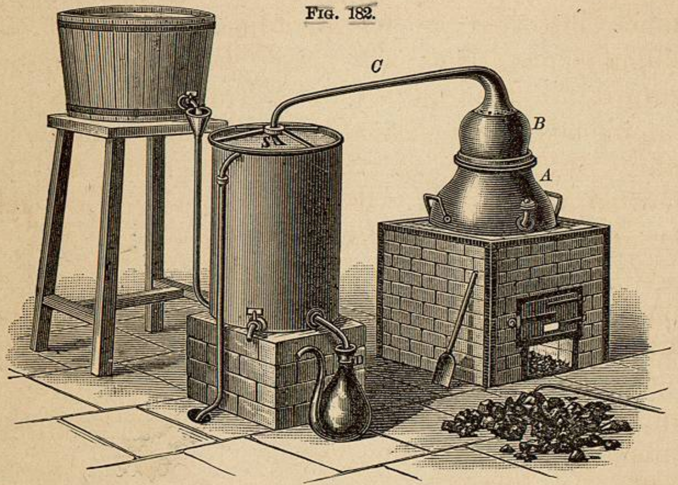
* That freezing is a warming process may be conclusively shown as follows: Gently melt some sodium sulphate (a cheap salt that may be obtained from any apothecary) in a flask by heating it over a lamp flame. Put it aside to cool slowly in a perfectly quiet place. After cooling it remains liquid, but ready to freeze as soon as motion among its molecules is started. Disturb it by putting a thermometer bulb into the liquid. At once crystals are seen shooting out, and the mass is soon frozen hard. The mercury in the thermometer meanwhile rises, and the warming may be felt with the hand.

ing-point, higher or lower than that of the liquid with which it is mixed.

FIG. 182.



A Still.

Boiling-point.—When we heat water, the bubbles which pass off first are the air dissolved in the liquid; next bubbles of steam form on the bottom and sides of the vessel, and, rising a little distance, are condensed by the cold water. Collapsing, they produce the sound known as "simmering." As the temperature of the water rises, they ascend higher, until they burst at the surface, and pass off into the air. The violent agitation of the water thus produced is termed boiling.* Some substances vaporize

at ordinary temperatures; others only at the highest; while the gases of the air are but the vapor of substances which boil at exceedingly low temperatures. The distinction between gases and vapors in ordinary language is only relative.

The boiling-point of water depends on three circumstances: (1.) *Purity of the water.* A solid substance dissolved in water ordinarily elevates the boiling-point. Thus salt water boils at a higher temperature than pure water. The air dissolved in water tends by its elastic force to separate the molecules. If this be removed, the boiling-point may be elevated to 275° F., when the water will be converted into steam with explosive violence.

(2.) *Nature of the vessel.* Water will boil at a lower temperature in iron than in glass. When the surface of the glass is chemically clean, the boiling-point is still higher. This seems to depend in some degree on the strength of the adhesion between the water and the containing vessel.

(3.) *Pressure upon the surface* raises the boiling-point.* Water, therefore, boils at a lower temperature on a mountain than in a valley. The temperature of boiling water at Quito is 194° F., and on

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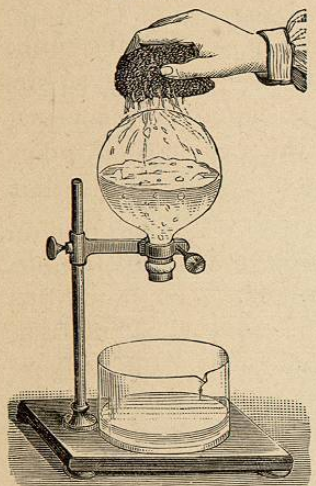
* The temperature of water can not be raised above the boiling-point, unless the steam be confined. The extra energy is applied in expanding the water into steam. This occupies 1,700 times the space, and is of the same temperature as the water from which it is made. Nearly 1,000° units of heat for each pound of water are expended in this process, but are made sensible again as temperature when the steam is condensed. Steam is invisible. This we can verify by examining it where it issues from the spout of the tea-kettle. It soon condenses, however, into minute globules, which become visible in white clouds.

* Pressure opposes the repellent heat-force, and so renders it easier for cohesion to hold the particles together. In the interior of the earth there may be masses of matter heated red or white hot and yet solid, more rigid even than glass, in consequence of their melting-point being raised so high by the tremendous pressure that they can not liquefy.—TAIT.

Mont Blanc, 183° F. The variation is so uniform that the height of a place can thus be ascertained; an ascent of 596 feet producing a difference of 1° F.

FIG. 183.



Boiling Water by Condensing its Vapor.

The influence of pressure is well illustrated by the following experiment: Half fill a strong glass flask with water, and boil this until all the air is expelled from both the water and the space above it. Now quickly apply a tight stopper and invert. The pressure of the steam will stop ebullition. A few drops of cold water will condense the steam, and boiling will recommence. This will soon be checked, but can be restored as before. The process may be repeated until the water cools to the ordinary temperature of the air, and even then the liquid inside may be made to boil by rubbing the outside of the flask with ice. The cushion of air which commonly breaks the fall of water is removed, and if the cork be air-tight, the water, when cold, will strike against the flask with a sharp, metallic sound.

6. Evaporation is a slow formation of vapor, which takes place at ordinary temperatures. Water evaporates even at the freezing-point. Clothes dry in the open air in the coldest weather. The wind quickens the process, because it drives away the moist air near the clothes and supplies dry air. Evaporation is also hastened by an increase of surface and a gentle heat.

Vacuum pans are employed in condensing milk and in the manufacture of sugar. They are so arranged that the air above the liquid in the vessel may be exhausted, and then the evaporation takes place rapidly, and at so low a temperature that burning is avoided.

The cooling effect of evaporation is due to the absorption of energy required to drive the molecules apart beyond their spheres of mutual attraction. Water may be frozen under the receiver of an air-pump by placing a small watch-glass containing it over a pan of strong sulphuric acid, which absorbs the vapor as fast as it is formed in the vacuum. The cooling due to rapid evaporation of a part is sufficient to freeze the rest. By strong pressure and cooling, carbonic acid is easily liquefied. Allowing a jet of this liquid to escape, the evaporation of a part of it causes the rest to freeze into a snowy powder which may be pressed into a ball.* Nitrogen, oxygen, and air, which is a mixture chiefly of these

* Mercury in contact with it is quickly solidified. On throwing the frozen metal into a little water, the mercury instantly liquefies, but the water turns to ice, the solid thus becoming a liquid and the liquid a solid by the exchange of heat. A cold knife cuts through the mass of frozen mercury as a hot knife would ordinarily through butter. The author, on one occasion, saw Tyndall, during a course of lectures at the Royal Institution at London, when freezing a ladle of mercury in a red-hot crucible, add some ether to hasten the evaporation. The liquid caught fire, but the metal was drawn out from the glowing crucible, through the midst of the flame, frozen into a solid mass.

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, $\frac{1}{8}$; 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.

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* 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.

I am so tired studying this hard lesson

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:*

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* 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.